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THE MARINE PLIOCENE AND PLEISTOCENE STRATIGRAPHY OF THE COAST OF SOUTHERN CALIFORNIA.

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INTRODUCTION.

The best development of the marine Pleistocene of the Pacific coast of North America is found along the coast of southern

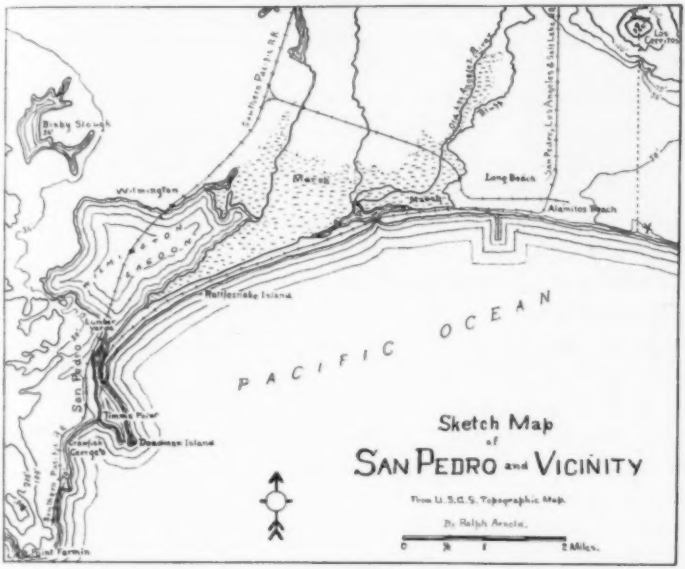
California, which extends from Point Concepcion on the north to San Diego on the south. A few references have been made by previous writers to the marine Pleistocene geology of western North America, but the inadequacy of their observations has failed to give a proper conception of the importance of the Pleistocene as developed along the southern California coast.

The field work upon which this paper is based has extended over a period of several years, during which time the writers have made a detailed study of the paleontology and stratigraphy of the Pleistocene and subjacent formations at San Pedro,[1] and have also visited and studied the formations at most of the localities from San Francisco to San Diego at which Pleistocene sediments are exposed. The deposits at San Pedro, being the best developed and most easily accessible, have been taken as the type series.

[1] The junior author has in press as a memoir of the California Academy of Sciences a paper entitled "The Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, with Notes on Similar Formations of the Adjacent California Coast."

SAN PEDRO — THE TYPE LOCALITY.

Topography.—The Pliocene and Pleistocene formations studied by the writers are confined to the lowest terrace of San Pedro Hill (see map of San Pedro and vicinity). This terrace extends from a point one-half mile east of Point Fermin to a bluff one-



half mile north of the business portion of San Pedro. A sea cliff averaging fifty feet in height bounds the terrace on the south, east, and north. Half a mile southeast of San Pedro is Deadman Island, a small fragment of the lowest terrace, fifty feet in height with an area on top of about eight hundred square yards. All of the formations exposed in the immediate vicinity of San Pedro are represented at Deadman Island, and it is this section which is taken as the type.

General geology.— The oldest formation in the lowest San Pedro terrace is the Monterey or Miocene shale series. These

shales, much contorted, are exposed along the sea cliff from Point Fermin to Timm's Point, and at Deadman Island, where they form the basement series. After the desposition of the Miocene shales the beds were elevated, contorted, and subjected to erosion. Following this a submergence took place during the Pliocene epoch, and a deposit of fine yellowish-brown, clayey sand was laid down on the surface of the eroded Miocene shales. The maximum thickness of this Pliocene at San Pedro is fifty feet.

In post-Pliocene times this sandstone was elevated and subjected to erosion; the Deadman Island and Timm's Point brown sands being all that is left of the Pliocene near San Pedro.

A later submergence brought the surface of the Pliocene again below sea level and deposits of fine gray sand, fossiliferous in places, were laid down on it. The maximum thickness of the gray sand formation at San Pedro is fifty feet. This gray sand formation rests unconformably on the Pliocene at Deadman Island, but is probably conformable with the Pliocene at Timm's Point. On account of its fauna, lithologic characteristics, and unconformable position on beds of late Pliocene age the gray sand formation, called the lower San Pedro series, is thought to be of Pleistocene origin.

A period of uplift more or less pronounced followed the deposition of the lower San Pedro series. This uplift brought about conditions favorable to the formation of lagoonal, sand dune, and shore deposits. These deposits, which are called the upper San Pedro series, consist of coarse gravels and sands, which are characterized by the abundance of their fossil contents, by false bedding, and by indications of the changing conditions which prevailed during the period of their deposition. Evidence which indicates that the upper San Pedro series rests unconformably upon the subjacent formations is found at all the outcrops of this formation which have been examined by the writers. The upper San Pedro gravels and sands rest upon the Miocene shales at Crawfish George's, on the Pliocene at Timm's Point, and on the lower San Pedro series at Deadman Island and the

San Pedro bluff, reaching its maximum thickness of twenty feet at the last locality.

An elevation which raised the San Pedro deposits to near their present level occurred after the deposition of the upper San Pedro series; then after remaining at a constant level for some time another small uplift took place, which left the beds in their present position. This last period of rest and subsequent elevation is evidenced by a raised beach formation four feet thick and six feet above the sea level on the north end of Deadman Island (see Fig. 1).

Pliocene.—The Pliocene at Deadman Island (see Fig. 1 and Plate I) consists principally of a series of fine brown clayey sand layers having a dip toward the north of eight to ten degrees and a thickness of forty-five feet. The bottom layer of this series, which rests on the eroded surface of the jointed Miocene shale, is a fossiliferous stratum twelve inches thick of water-worn shale pebbles and sand. Many of the shale pebbles, and the surface of the eroded shale, show worm and pholas borings. About eight feet of fine yellowish-brown, rather incoherent, clayey sand rests on the gravel stratum. Well-preserved fossils are abundant in some parts of the clayey stratum. Four feet of hard, fine, porous, brown sandstone overlie the clayey stratum. Fossils are common in this hard bed, the most fossiliferous places being the harder, due to the cementing effect of the lime from the shells. On account of the great abundance of *Thyasira* (= *Cryptodon*) *bisecta* in this hard stratum it has received the local name of "Cryptodon bed." Twenty-five to thirty-five feet of faintly laminated brown sandstone overlie the Cryptodon bed. These uppermost brown sands are characterized by beautiful specimens of *Pecten caurinus*, *Lucina acutilineata*, and *Panomya ampla*.

The fauna of the Deadman Island Pliocene is somewhat similar to the fauna which is now living in twenty to fifty fathoms off shore from San Pedro. The Pliocene sediments are also analogous to the mud and fine sand now found on the bottom off the San Pedro shore. It is, therefore, safe to assume that

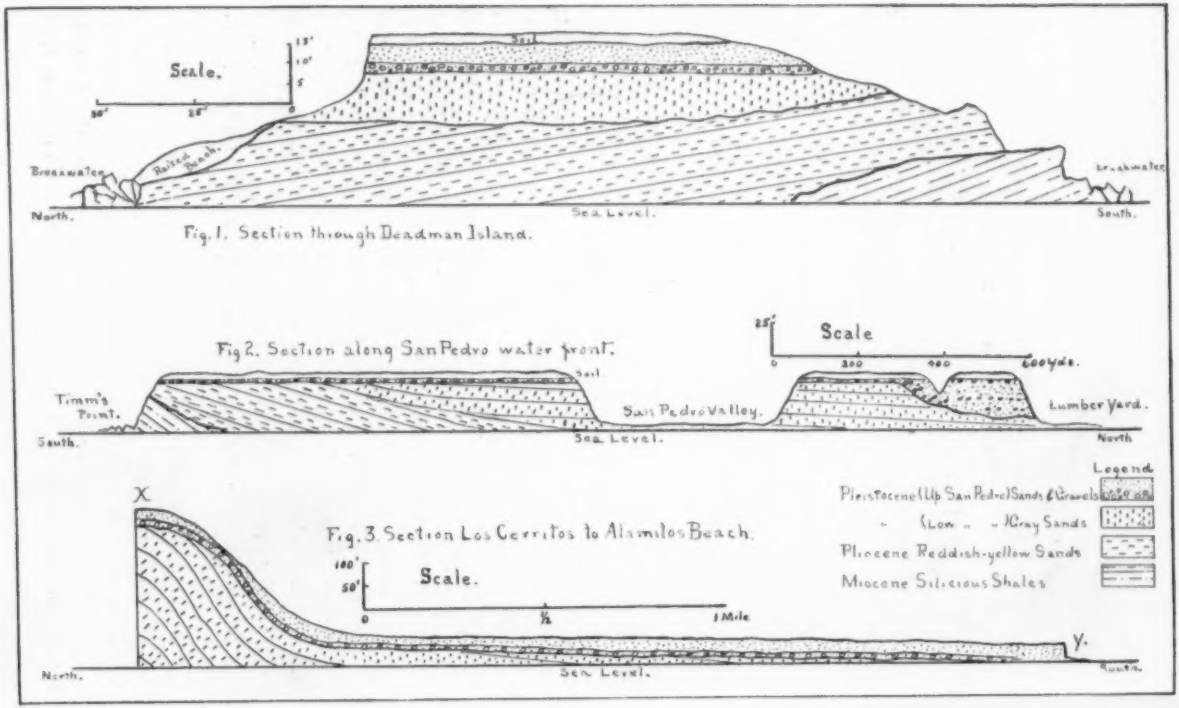

Scale.
15'
10'
5'
50'
25'
0
Soil
Breakwater
Raised Beach.
Breakwater
North.
Sea Level.
South.
Fig. 1. Section through Deadman Island.
Fig 2. Section along San Pedro water front.
25'
Scale
0
200
400
600yds.
Soil
Timm's Point.
San Pedro Valley.
Lumber Yard.
South.
Sea Level.
North
Legend.
Pleistocene (Up San Pedro) Sands & Gravels
(Low ") Gray Sands
Pliocene Reddish-yellow Sands
Miocene Siliceous Shales
X
Fig. 3. Section Los Cerritos to Alamitos Beach.
100'
50'
Scale.
0
½
1 Mile
Y.
North.
Sea Level.
South.

PLATE Ia.—West face of Deadman Island, looking east, showing Miocene, Pliocene, and Pleistocene formations (see Fig. 1 for explanation).

PLATE Ib.—North end of Deadman Island, looking east, showing nonconformity between Pliocene and lower San Pedro (Pleistocene) gray sands (see fig. 1 for explanation).

the Deadman Island Pliocene was deposited under conditions somewhat analogous to those now prevailing in the ocean off San Pedro at depths of from twenty to fifty fathoms. There is a marked difference, however, between the Pliocene fauna and that now living off San Pedro, the former being characterized by the abundance of the individuals and species which are now found living only far north of San Pedro. To state it more precisely, out of the Pliocene fauna of eighty-seven species, 18.5 per cent. are found living now only north of San Pedro, and nearly all of the remaining species yet living show a decided predilection for boreal or subboreal conditions. The occurrence in large numbers in the Deadman Island Pliocene of *Pecten caurinus*, *Panomya ampla*, *Thyasira bisecta*, *Pecten hericeus*, *Lucina acutilineata*, *Natica clausa*, several species of *Trophon* and northern *Pleurotomidæ*, and other boreal and subboreal forms leads to the conclusion that these Pliocene strata were deposited in water much colder than that which is now found in the vicinity of San Pedro. Boreal or subboreal conditions so near the shore imply boreal or subboreal climatic conditions on the land, at least near the ocean. This being true, it is safe to assume that, during the latter part of the Pliocene epoch, the climate was much colder on the coast of southern California than it is at present.

The lowest, or brown sandstone, series of Deadman Island is called Pliocene for several reasons. First, it overlies unconformably the Miocene shales, from which it differs widely both lithologically and faunally. Second, it contains a fauna over 12 per cent. of which are extinct species, and many of the remaining species are those now found living only in places remote from San Pedro. This evidence precludes any possibility of its being Pleistocene. Third, the general aspect of the fauna is quite similar to that of the British Crag (Pliocene). That the Deadman Island Pliocene belongs to the latter part of that epoch is evidenced by its fauna, which gradually grades into that of the typical Pleistocene through that of the overlying lower San Pedro (Pleistocene). The gap between the Deadman Island Pliocene and Pleistocene is distinct, though not wide.

Dr. Dall[1] says of this Pliocene horizon: "It appears that on Deadman Island, near Point Fermin, at least three distinguishable strata appear, the uppermost of which is certainly Pleistocene, while the others are Neocene, and the middle layer probably Pliocene."

The brown Pliocene sandstone formation outcrops at Timm's Point (see Fig. 2), on the western side of San Pedro Bay. Here it lies unconformably on the Miocene shales as at Deadman Island; but its stratigraphic relation with the overlying lower San Pedro (Pleistocene) beds is not so easily determinable, although the faunal break between the two formations is as pronounced as at Deadman Island.

Pleistocene: the San Pedro series.—The evidence brought forward in this paper demonstrates that most of the marine Pleistocene as developed on the Pacific coast is represented by the strata of Deadman Island and San Pedro. The writers, therefore, propose the name San Pedro series for all of the strata of Deadman Island and San Pedro lying stratigraphically above the brown Pliocene sandstone formation and below the raised beach formation of Deadman Island. The San Pedro series may be divided into two distinct horizons, a lower and an upper, separated at all points in the vicinity of San Pedro by an unconformity.

Lower San Pedro series.—A stratum of gray sandstone averaging about twelve feet in thickness rests unconformably upon the brown Pliocene sandstone at Deadman Island (see Fig. 1). This gray sandstone is incoherent in some places but very firmly cemented in others, the harder portions usually being the more fossiliferous. No bedding is visible in the gray sand, but the formation lies nearly horizontal. This lower San Pedro stratum at Deadman Island, and also the contemporaneous strata in the San Pedro bluffs (see Fig. 2), as indicated by their lithologic characters and fauna, were deposited in water shallower than that in which most of the underlying brown Pliocene

[1] W. H. DALL and G. D. HARRIS, *Correlation Papers: Neocene. U. S. Geol. Surv., Bull. No. 84*, p. 216, 1892.

strata were laid down. The sediments consist for the most part of medium grained gray sands, such as are being deposited at the present time quite near shore off San Pedro. The abundance in the lower San Pedro deposits of certain species which live only between tides also offers evidence of deposition of the strata near the shore.

The fauna of the lower San Pedro series is one of transition from the boreal or subboreal fauna of the late Pliocene to the semi-tropical fauna of the upper San Pedro series. Two causes account for this change: (1) The deposits being laid down in shallower water than that in which the Pliocene sediments were deposited would necessarily contain fewer of the colder, deeper water forms of the Pliocene; and (2) the lower temperature prevailing during the latter part of the Pliocene epoch was giving place to warmer conditions, which caused the boreal species to migrate and brought in more of the species which commonly inhabit warm waters. Of the fauna of nearly 250 species found in the lower San Pedro series, over 17 per cent. are now found living only north of San Pedro. This percentage is only a little lower than that of the northern species found in the Pliocene, (the latter being 18.5 per cent.), and indicates, considering the fact that the lower San Pedro beds are shallower water deposits than those of the Pliocene, that the climatic conditions had changed but little during the period, intervening between the deposition of the Pliocene and the overlying lower San Pedro series.

The evidence afforded by several species in the lower San Pedro series (about 4 per cent. of the fauna of that series), which are now found living only south of San Pedro, shows that the conditions were changing from cold to warm. Besides the distinctly northern forms which either disappear or become scarce in the period between the Pliocene and lower San Pedro, there are many species now more commonly found in northern waters, which, though common in the Pliocene, become rarer in the Pleistocene; while species showing a predilection for southern conditions become common in the fauna of the latter period.

All of the evidence shows that the conditions were changing from boreal toward subtropical during the time just preceding and during the deposition of the lower San Pedro series; but boreal conditions still predominated.

This series is placed in the Pleistocene primarily upon paleontologic evidence. The low percentage of extinct species and the occurrence of the three living echinoderms *Strongylocentrotus purpuratus*, *S. franciscanus*, and *Echinarachnius excentricus* offers strong evidence of the Pleistocene age of this series, the three species of echinoderms having never been found in any of the beds on this coast commonly accepted as Pliocene. The general aspect of the deposits, the state of preservation of the fossils, and the unconformable position of the lower San Pedro series on upper Pliocene beds strengthen the faunal evidence.

These beds are exposed in the bluffs north of Timm's Point (see Fig. 2), where they rest on the brown Pliocene sandstone and are overlain unconformably by the upper San Pedro gravels. There is some doubt as to the relation between the Pleistocene and the underlying Pliocence in these bluffs, although most of the available evidence is in favor of the conformability of the two formations.

Upper San Pedro series.—The gray sandstone of the lower San Pedro series at Deadman Island (see Fig. 1) is overlain unconformably by a three-foot stratum of fossiliferous gravel hardened by lime, above which are about seven feet of fine sand. This gravel stratum and the overlying sand makes the upper San Pedro series at Deadman Island. The gravel stratum is continuous over nearly the whole of the lower, or fifty-foot, San Pedro terrace, and at nearly every exposure it is seen to lie unconformably upon the subjacent beds. This evidence shows that the deposition of the upper San Pedro beds followed a period of erosion. The best development of the upper San Pedro series is found in the bluff at the lumber yard north of San Pedro (see map of San Pedro, and also Fig. 2), where the alternating fossiliferous beds of gravel and sand attain a thickness of twenty feet.

San Pedro. Peculiar nonconformity between lower and upper San Pedro series (Pleistocene) beds, in water front bluff south of lumber yard (photographs by Dr. H. W. Fairbanks).

The deposits of the upper beds in the vicinity of San Pedro consist for the most part of coarse gravels and sands which show alternating dune and water bedding, and have the appearance of having been laid down during a period of rapidly changing conditions.

The fauna of the upper beds is southern in character, and, as would be expected, approaches more nearly the present living fauna of the San Pedro region. Since the fauna of the upper beds inhabited shallower water than that in which either the Pliocene or lower San Pedro faunas lived, one would expect to find in it fewer of the cold water forms and more of the species found between tides and in the warm shallow waters of lagoons. Such is the case, but further, it is a noticeable fact that in the upper beds over 14 per cent. of the fauna are species which are now found living only south of San Pedro. This is not only true, but of those species found in the upper beds which are still living at San Pedro, a great majority are forms which are commoner in the waters south of that place.

Although over 6 per cent. of the upper San Pedro fauna are found now living only north of San Pedro, these northern species are only very rarely found in this formation. On the other hand most of the distinctly southern forms and those which, though now living at San Pedro are commoner further south, are commoner in the upper beds, thus giving it a semitropical aspect. Such species as *Cardium elatum*, *Arca labiata*, *Pecten dentatus*, *Mactra exoleta*, *Venus gnidia*, *Murex leeanus*, *Eupleura muriciformis*, *Cancellaria tritonidea*, and *Bulla punctulata* give this fauna its southern character. The evidence afforded by the southern forms outweighs the evidence of the northern species in another respect, for it would require a great change in conditions from those prevalent during later Pliocene times to cause these southern species to migrate northward to the San Pedro region; while this same change in condition would not so materially affect the northern species, for they could simply migrate into deep water where the conditions would more nearly approximate the boreal. This latter has been the case with such species as *Lucina acuti-*

lineata, *Chrysodomus tabulatus*, *Solariella cidaris*, and *Solariella peramabilis*, which now inhabit northern waters near shore, but which have been dredged in the deep water between Catalina Island and the mainland.

The upper San Pedro series is separated from the lower for three reasons: (1) on account of the unconformity existing between the two; (2) on account of the difference in their lithologic characters, the former consisting of gravels or coarse sands, while the latter is made up wholly of rather fine gray sands; and (3) because of the great difference in the faunas of the two; that of the former being one indigenous to warm water, that of the latter, one which is now found living where subboreal conditions prevail.

The occurrence of Pleistocene deposits younger than the upper San Pedro beds at several points along the coast, and the crustal movements and elevation of the coast that have taken place at several places since the deposition of the upper San Pedro beds indicate that quite a long period of time has elapsed since the latter were laid down.

A raised beach on the north end of Deadman Island (see Fig. 1), six feet above sea level and four feet thick affords evidence of another period in the Pleistocence. The shells in this deposit are the same as those found in the beach at Deadman Island at the present time, and the most of them retain their original coloration. This raised beach represents a very late Pleistocene horizon.

Post-Pleistocene Deposits.—The marine deposits of Deadman Island and the San Pedro terrace are overlain by alluvial deposits which contain large quantities of shells in certain places. These shell heaps are ancient Indian kitchen middens. Shells of a kind that would be used for food, such as *Haliotis cracherodii*, *Pecten æquisulcatus*, *Chione succincta*, *Tivela crassatelloides*, *Tapes staminea*, *Saxidomus aratus*, and others are found mixed with pieces of charcoal, flint chips and animal remains in these ancient accumulations. These Indian kitchen middens are often mistaken for fossil deposits, especially the one at Port

Harford, San Luis Obispo county, where the deposits of shells in the adobe soil attain a thickness of over six feet.

SAN DIEGO.

General geology.—Next to San Pedro, the best development of the marine Pleistocene of Southern California is found in the vicinity of San Diego. The geologic history of San Diego has been somewhat similar to that of the San Pedro region. During late Pliocene times the territory now occupied by San Diego Bay and the region to the northwest was occupied by an arm of the sea in which were deposited several hundred feet of coarse gravels, and these in turn were overlaid by fine grained sandstones. An uplift took place at the close of the Pliocene or in early Pleistocene times, followed by a period of erosion during which the terrace or mesa which extends from San Diego to Pacific Beach was planed off. Following the period of uplift a slight depression took place, and the gravels and sands of the upper San Pedro series (Pleistocene) were laid down on top of the eroded Pliocene sandstone. Since the deposition of the latest beds an uplift of at least fifty feet has taken place.

Pliocene.—The writers have examined the Pliocene strata at Pacific Beach, and near the Russ School (San Diego well). The Pliocene at Pacific Beach makes the lower part of the sea cliff which begins at Ocean Front and extends northward for at least a mile and a half (see Fig. 4). Two hundred feet of yellowish-brown sandstone, dipping south at an angle of about 10 degrees and overlain unconformably by Pleistocene gravel, are exposed in this section. The upper layers of the sandstone are fossiliferous, while the lower portion, which rests on an unknown thickness of coarse gravels, is without fossils.

There are two horizons in the fossiliferous section of the sandstone which may be separated upon paleontologic evidence. The lower horizon comprises all of the exposed fossiliferous beds with the exception of the uppermost three or four. It is characterized by a unique fauna among which are found the following species which are not known outside of the San Diego

province: *Pecten expansus*, *Pecten subventricosus*, *Opalia varicostata* and *Opalia anomala*. This lower horizon is correlated with the Deadman Island Pliocene. The upper horizon is characterized by *Pecten hemphilli*, *Crepidula grandis*, *Macoma secta*, *Echinarachnius excentricus* and *Strongylocentrotus purpuratus*, and is correlated with the lower San Pedro series (Pleistocene).

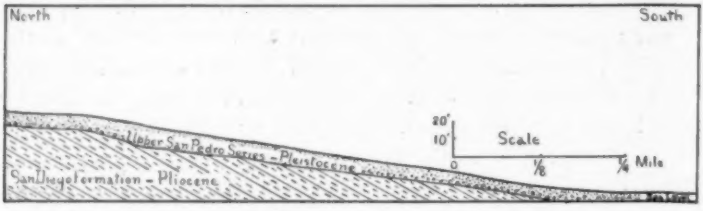


FIG. 4.—Section along Pacific Beach, near San Diego, showing the relation between the San Diego formation (Pliocene) and the upper San Pedro series (Pleistocene).

A formation similar to that of the Pacific Beach Pliocene outcrops near the Russ School, in the northern part of San Diego. The San Diego well, which is located just south of this outcrop, gives an instructive section of this Pliocene series. The well is at the bottom of a ravine (see Fig. 5), the sides of which are of

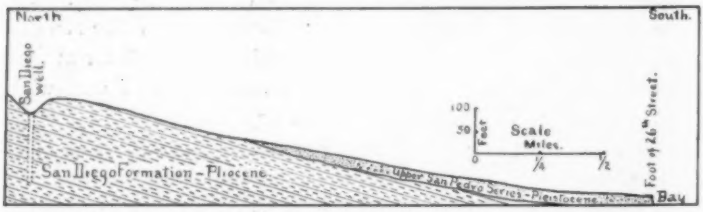


FIG. 5.—San Diego. Section from San Diego well to bay at foot of Twenty-sixth street, showing relation of San Diego formation (Pliocene) to upper San Pedro series (Pleistocene).

strata containing a fauna similar to that of the upper Pliocene horizon at Pacific Beach. The strata above the well dip gently south toward San Diego Bay. The well is 149 feet deep,[1] and

[1] The writers are indebted to Mr. Henry Hemphill, who collected fossils from the San Diego well during the course of its excavation, for the data concerning it.

Pacific Beach. San Diego formation (Pliocene) overlain unconformably by upper San Pedro (Pleistocene) gravels (see fig. 4 for explanation).

penetrates fossiliferous strata for its entire depth. The lowest beds are below the lower fossiliferous horizon of Pacific Beach, and are characterized by the large *Arca schizotoma* Dall (=*A. sulicosta* Gabb).

Pleistocene.—The tilted brown sandstone of Pacific Beach is overlain unconformably by a layer of fossiliferous gravel and sand from two to fifteen feet thick (see Fig. 4), which probably covers much of the terrace of which the Pacific Beach sea cliff is the bounding escarpment. In this respect the gravel layer is similar to the gravel stratum which covers the San Pedro terrace. The gravel and sand series is characterized by a fauna which is entirely different from that of the underlying sandstones, but which is almost identical to the fauna of the upper beds of San Pedro. Upon this evidence the gravel and sand layers are placed in the upper San Pedro series.

At the foot of Twenty-sixth street (see Fig. 5), and at Spanish Bight, beds of rather incoherent sands and fine gravels are exposed in the bluffs which form the shore line of the bay at these localities. These beds are richly fossiliferous, the fauna being similar to that of the upper San Pedro series at San Pedro, with which the Twenty-sixth street and Spanish Bight beds are correlated.

REGION BETWEEN SAN DIEGO AND SAN PEDRO.

The sea cliffs from a few miles north of Pacific Beach to near Newport are composed for the most part of soft dark colored shales and incoherent sandstones and gravels of late Pliocene and Pleistocene age. These deposits are mostly horizontal, but have been elevated in places to several hundred feet above sea level.

W. L. Watts[1] reports a formation, probably contemporaneous with the San Diego formation, at San Juan Capistrano in which the remains of a mastodon were found. Mr. Watts[2] has also reported

[1] W. L. Watts, "Oil-and Gas-Yielding Formations of California," *Bull. No. 19, Cal. State Mining Bureau*, pp. 59, 222, 1900.

[2] *Op. cit.*, pp. 61, 223.

deposits in the vicinity of Newport, which, from their fossil contents, have been correlated with the upper San Pedro series (Pleistocene) by the writers.

At Bell Station,[1] near Los Angeles, a typical lower San Pedro (Pleistocene) fauna was obtained from a well between the depths of 920 and 1,320 feet. This shows the amount of sedimentation that has taken place in the Los Angeles basin during part of the Pleistocene epoch.

Gravels containing a typical upper San Pedro fauna are found at an elevation of about 350 feet on Los Cerritos Hill, near Long Beach (see map of San Pedro). The gravel stratum dips away from the top of the hill towards the ocean, and is part of the same series of sediments which is exposed in the sea cliff in front of Long Beach and Alamitos Beach (see Fig. 3).

REGION BETWEEN SAN PEDRO AND VENTURA.

The only locality between San Pedro and Ventura which has been examined by the writers is near Port Los Angeles. At this locality the sea cliff is nearly two hundred feet in height, the upper portion being composed of rather incoherent unfossiliferous sands and gravels probably of upper San Pedro (Pleistocene) age. These upper beds overlie, probably unconformably, hard strata of sandstone which contain a fauna similar to that found in the lower San Pedro series at Deadman Island.

VENTURA.

The most important fact about the geology in the vicinity of Ventura is the great thickness, steep inclination, and great elevation above the sea of the upper San Pedro (Pleistocene) sediments. The range of hills north of Ventura, which have an elevation of from five hundred to one thousand feet above sea level and which extend for several miles east and west of that city, are composed for the most part of soft, thickly laminated, yellowish-brown sandstones dipping away from the axis of the range. Along the old irrigating ditch which skirts the hills east of Matilleja Valley, west of Ventura (see Fig. 6), there is an

[1] W. L. WATTS, *op. cit.*, p. 233.

Ventura. Wave-cut terraces in Pleistocene sediments one mile west of Ventura.

exposure of over one thousand feet of these soft sandstones, tilted at an angle of from 40 to 50 degrees toward the ocean. The fauna of these beds indicates their contemporanity with the upper San Pedro series, although the fauna near the bottom resembles more that of the lower San Pedro. A fauna of over sixty recognizable species was obtained from soft beds in the hills north of Barlow's ranch, three miles east of Ventura, at an elevation of between seven and eight hundred feet. The strata from which these fossils came are inclined at an angle of over 40°,

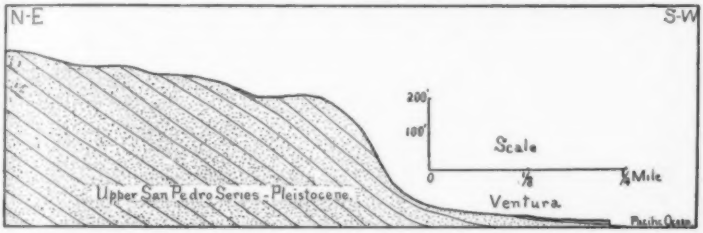


FIG. 6.— Section through Ventura, showing thickness of upper San Pedro series (Pleistocene) sediments, and a wave-cut terrace in the sediments.

but are not contorted. The fauna is typically upper San Pedro, all of the sixty species (with the possible exception of one which is a variety of a living species) being living forms.

Wave-formed terraces plane off the Pleistocene beds in the hills about a mile west of Ventura (see Plate 5). These terraces represent a period of time later than the upper San Pedro, and are probably of late Pleistocene age. The accumulation of comparatively great thicknesses of sediments, their elevation to at least one thousand feet, and their configuration by wave-cut terraces shows how active the geologic agencies have been in the vicinity of Ventura during comparatively recent times.

The region along the coast from Ventura to Santa Barbara is characterized by unfossiliferous, incoherent sands and gravels probably of Pleistocene age. Some of these sands and gravels are impregnated with asphaltum from the underlying Miocene shales.

SANTA BARBARA.

The later deposits in the vicinity of Santa Barbara resemble quite closely those of San Diego. At Packard's Hill, west of Santa Barbara, a thickness of over two hundred feet of alternating hard and soft beds of brown sandstone is exposed. These beds have a dip of S. 30° W. 50° toward the ocean. They are correlated by the writers with the Deadman Island Pliocene. Their fauna, however, shows a greater resemblance in some respects to the fauna of the San Diego formation (Pliocene).

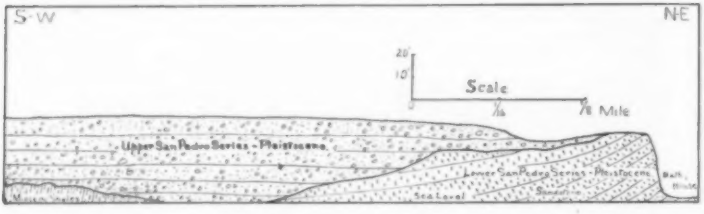
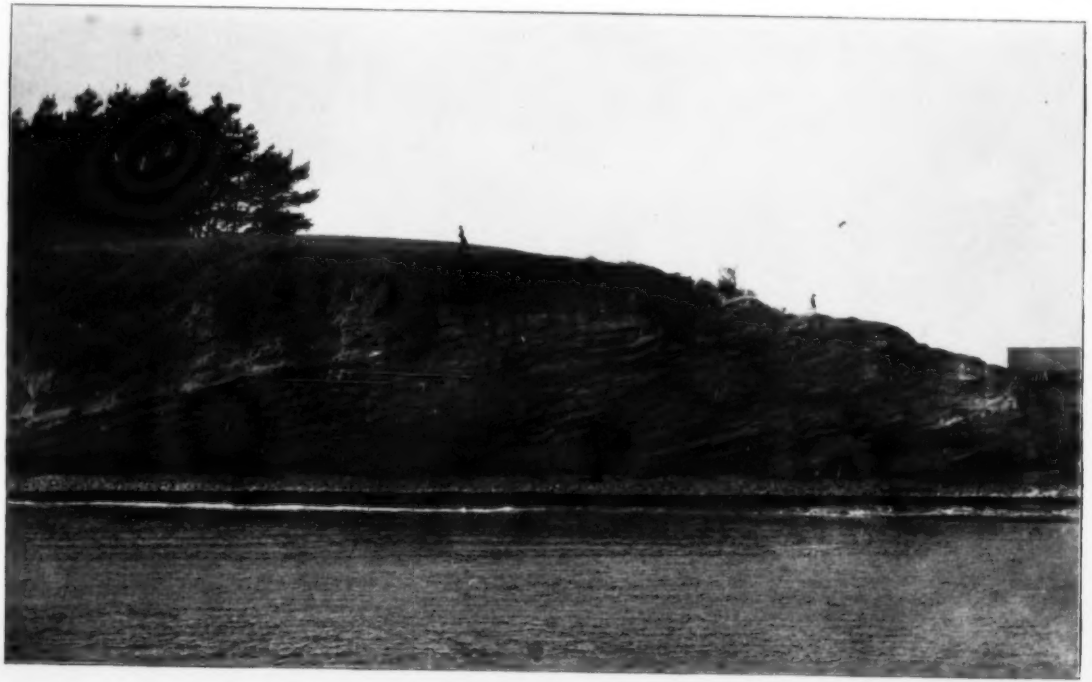


FIG. 7.—Santa Barbara. Section along coast southwest of bath house, showing relation between the Miocene and lower and upper San Pedro series (Pleistocene).

A thickness of thirty feet of alternating hard and soft beds of sandstone and sandy marl are exposed in the bluff west of the bath house on the Santa Barbara ocean front (see Plate V and Fig. 7). These strata are quite similar lithologically to the Packard's Hill Pliocene and probably lie conformably above it. The fauna of the bath house beach beds is more recent than that of the Packard's Hill deposits, and contain *Strongylocentrotus purpuratus*, *Echinarachnius excentricus*, and several other Pleistocene species not found in the Pliocene. Upon paleontological evidence the bath house beach deposits are correlated with the lower San Pedro series.

Beds of unfossilferous gravel and sand are exposed in the bluff west of the bath house beach fossiliferous strata. In some places these beds overlie the fossiliferous strata, while in others they overlie the basement series of Monterey shale. These sands and gravels, which are correlated with the upper San



Santa Barbara. Lower San Pedro (Pleistocene) strata west of bath house (see Fig. 7 for explanation).

Pedro series, are probably unconformable with the lower fossilif erous strata (a fossiliferous fragment of the latter being found in the former) although the exact relation between the two horizons was not definitely determinable stratigraphically, owing to the prevalence of false bedding in the upper beds. Asphaltum impregnates the gravels and sands in several places where they rest upon the Miocene shales. An Indian kitchen midden overlies the Pleistocene deposits one-eighth of a mile west of the bath house.

RELATION BETWEEN THE SOUTHERN CALIFORNIA PLIOCENE AND PLEISTOCENE AND THE MERCED SERIES.

A series of sandstones and shales over five thousand feet in thickness is exposed in the sea cliff which extends for a few miles south of Lake Merced on the San Francisco peninsula. This series of beds has been described by Dr. A. C. Lawson,[1] who named it the Merced series. Dr. Lawson places the whole series, with the exception of about one hundred feet of strata at the top, in the Pliocene. Dr. G. H. Ashley[2] draws the Pliocene-Pleistocene line further down in the series, or at the base of a fossiliferous stratum which has received the local name "upper gastropod bed." A study of the faunas of the different layers of the merced series has led the writers to draw the line in the same place that Dr. Ashley has drawn it. Although there is a distinct faunal break between the "upper gastropod bed" and the subjacent layers, there seems to be no indication of any decided interruption in the sedimentation in this part of the series.

Dr. Dall[3] places the San Diego formation, with which he correlates the Deadman Island Pliocene, below the Merced series. This does not agree with the conclusions arrived at by

[1] A. C. LAWSON, "The Post-Pliocene Diastrophism of the Coast of Southern California," *Bull. Dept. Geol., Univ. of Cal.*, Vol. I, pp. 142–50, 1892.

[2] GEORGE H. ASHLEY, "The Neocene of the Santa Cruz Mountains, *Proc. Cal. Acad. Sci.*, 2d Series, Vol. V, pp. 312–37, 1895.

[3] W. H. DALL, "Correlation Table of North American Tertiary Horizons," *Eighteenth Ann. Rep. U. S. Geol. Surv.*, Pt. II, p. 335, 1898.

the writers after a study of the stratigraphy and faunas of the formations under discussion. The San Diego formation, with which are correlated the Deadman Island Pliocene and the Santa Barbara (Packard's Hill and bath house beach) formations are placed in the upper part of the Merced for the following reasons: (1) the strata of the Merced series wherever examined by the writers show much more contortion than the strata of the San Diego formation or its equivalents; (2) the fauna of Deadman Island Pliocene grades over by easy stages into the fauna of the Pleistocene with only a slight break between the two, thus precluding the possibility of the intercalation of such a distinctive fauna as that of the Merced series between the Deadman Island Pliocene (equivalent of the lower San Diego formation) and the San Pedro series (Pleistocene); (3) the occurence in only the very uppermost layers of the Merced series of *Echinarachnius excentricus*, which is found in the upper horizon of the San Diego formation; and the total absence of the common Merced echinoderm, *Scutella interlineata*, from the San Diego formation and all of its equivalents and overlying beds; (4) the abundance at the very bottom of the San Diego formation (in the lowest part of the San Diego well section only) of the typically characteristic middle Merced pelecypod *Arca schizotoma* Dall (=*A. sulicosta* Gabb).

The probability of an overlap of the time periods represented by different formations, Merced, San Diego, and San Pedro, is considerable; in fact the term Merced series, as used by Lawson, probably includes nearly, if not all, of the San Diego formation, and probably part of the San Pedro series.

The following correlation table gives the relation between the different formations of the Pliocene and Pleistocene of the coast of California as understood by the writers.

CONDITIONS PREVALENT DURING THE PLIOCENE AND PLEISTOCENE.

Basing the conclusions upon the evidence offered by the faunas of the Pliocene and Pleistocene formations it is seen that there has been a fluctuation of conditions along the California

CORRELATION TABLE

OF THE UPPER PLIOCENE AND PLEISTOCENE FORMATIONS OF SOUTHERN CALIFORNIA.

[NOTE. — Wavy lines show conformability; straight lines, unconformability.]

TOTAL THICKNESS.	PLIOCENE.	PLEISTOCENE.			EPOCH.
	SAN DIEGO FORMATION.				FORMATION.
	Lower.	Upper.			
		SAN PEDRO SERIES.		RECENTLY RAISED BEACH'S.	
		Lower.	Upper.		
	MERCED SERIES.				
PLEISTOCENE, 70 PLIOCENE, 180	San Diego well. 150′	Russ School. 50′	Foot of 26th street. 20′		SAN DIEGO SECTION.
			Spanish Bight. 20′		
	Pacific Beach (lower horizon). 180′	Pac. B. (up. hor.) 20′	Pacific Beach. 15′		
PLEISTOCENE, 100′ PLIOCENE, 50′	Deadman I. 45′	Deadman Island. 12′	Deadman Island. 10′	D'man I. 4′	SAN PEDRO SECTION.
	Timm's Point. 50′	San Pedro Bluffs. 50′	Lumber yard. 20′		
			Crawfish George's. 3′		
		Los Cerritos Hill. 50′	Los Cerritos Hill. 20′		
			Long Beach. 50′		
PLEISTOCENE. 1000′+		Old irrigating ditch (?)	Old irrigating ditch. 1000′+		VENTURA SECTION.
			Barlow's ranch, 100′+		
PLEISTOCENE. 60′ PLIOCENE. 300′+	Packard's Hill. 200′+	Bluff at bath house. 30′	Bluff ¼ mile west of bath house. 25′		SANTA BARBARA SECTION.
			Bluff 2 miles east of wharf. 30′		
PLEISTOCENE. 350 ± PLIOCENE. 5000′+	Section from Lake Merced to Mussel Rock below the "upper gastropod bed." 5000′+	"Upper gastropod bed" to nonconformity. 150′±	Strata above nonconformity ("terrace formation"). 200′±		LAKE MERCED SECTION.
MAXIMUM PLEISTOCENE, 1320′ (BELL'S STATION). MAXIMUM PLIOCENE, 5000 (LAKE MERCED).	San Juan Capistrano.		Newport, Orange county.		OTHER LOCALITIES.
			Bell's Station, Los Angeles county. 1320′		
		Port Los Angeles, fossiliferous horizon. 50′±	Port Los Angeles, upper unfossiliferous beds. 150′		
			San Pablo Bay, Contra Costo county. "Oyster beds."		
			Fort Ross, Humboldt county.		

coast since the beginning of Pliocene times. The San Pablo (middle Neocene) and Merced faunas contain an abundance of such genera as *Arca*, *Dosinia*, *Pinna* and other southern forms which indicate that southern or warm conditions prevailed during the period of deposition of those two formations. Following the Merced (or, more strictly speaking, the middle of the Merced) comes the San Diego formation with its fauna of such northern species as *Pecten caurinus*, *Panomya ampla*, *Purpura crispata*, several species of *Trophon* and many other species indigenous to northern waters, which shows that northern or boreal conditions prevailed during the later Pliocene and early Pleistocene times. The transition from the boreal conditions of the late Pliocene to the semitropical conditions of the upper San Pedro series (typical Pleistocene) is indicated by the transition fauna of the lower San Pedro series. The upper San Pedro fauna contains so many southern species that it is safe to assume that conditions more nearly approximating those of the coast of Mexico at the present time, prevailed along the coast of southern California during that part of the Pleistocene in which the upper San Pedro beds were deposited. Since these latter strata were deposited a slight change has taken place, and the conditions now prevailing were inaugurated.

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INDIVIDUALS OF STRATIGRAPHIC CLASSIFICATION: DISCUSSION.

THE exceedingly suggestive paper appearing in a recent number of the JOURNAL,[1] under the above title, brings up for discussion some of the very practical problems which confront the geologist in his daily work. Their importance will perhaps warrant a supplementary discussion of the subject from the point of view of the mining geologist; not that this is necessarily the most important point of view, but rather that geologists in their devotion to the interests of pure science are apt to overlook the needs of fellow workers in applied science. The debt of science, as expressed in the generous appropriations of the various states and the general government for geological surveys and similar institutions, is too great to warrant us in failing at any time to give the highest possible return in practical results. While the great purpose of geologic science, to reconstruct the past history of the earth, must be kept steadily in view, it is well, if we would have the means to carry on that work, that we should keep no less steadily in view the wants of the plain citizens who are developing our country's resources.

The paper in question is particularly welcome to the mining geologist because it emphasizes the importance of mapping many of those features which will help him most in directing the development of mines and mineral deposits. One engaged in such work needs somewhat more complete data in regard to the lithology of the rocks and the geographical distribution of the more minute rock units than are necessary for ordinary geological research. He needs also a very minute knowledge of local structure and as perfect a knowledge as may be of the processes of change through which the rocks have passed.

In studying the genesis of any ore deposit it is needful, first,

[1] BAILEY WILLIS, *Individuals of Stratigraphic Classification*, JOUR. GEOL., Vol. IX, No. 7, October-November, 1901, pp. 557–69.

to determine, if possible, the exact conditions under which the country rock was laid down, so as to know what the original content of the rock in mineral is likely to have been. Since the conditions under which deposits accumulate are reflected in the character of the material accumulated, lithology is of primary importance at this stage of the investigation. In the second place it is important to determine the changes which the rock has undergone since its original formation. This at once leads into the general study of metamorphism, and again the expression of the results is best accomplished by lithologic mapping. Since, however, different materials under the same or different processes of metamorphism may produce rocks which in their final stages are lithologically identical, a map to express the full facts must be constructed so that by means of various colors, patterns, symbols, or prefixes in the legend, the lithologically similar but historically different rocks may be readily distinguished. The structure of the region must be thoroughly understood before any general plan of development can be formulated. All these facts can and should be represented upon any geological map intended for the use of a mining population.

In general the mining geologist is called upon to do two things: (1) to report upon some mine or tract of presumably mineralized land in order to determine whether the showing warrants the undertaking of development work; (2) to direct the further development of mines already partially opened up. In reporting upon properties he is oftenest sent to regions which are very little developed and which generally are not geologically mapped. In such a region he must rely in the first instance upon such reconnoissance maps as may be available, but in the main upon his own efforts. In the nature of the case the first detailed mapping in mineral districts must in a majority of instances be the result of individual initiative. The maps made in this way are more detailed than official maps can be expected to be, but they are also entirely unrelated, and each covers a very limited territory. So far, then, as the primary develop-

ment of mineral districts is concerned, reconnoissance maps are the best that can be rightly expected by the mining geologist. For his purpose it is more important that he should have such maps of the whole country, and that such facts as are represented on them shall be accurate, than that they should show great detail. For example, if such a map shows the presence of limestone and porphyry, together with a structure generally similar to that of the Leadville district, he will feel warranted in having prospecting undertaken within the area. The exact distribution of the limestone and porphyry areas is a very minor consideration, and errors in this particular will not greatly injure the usefulness of the map. A mining company must always make independent and careful surveys in any event in locating and patenting the property.

Since it is generally true that rocks of the same age are apt to bear the same or related minerals, any suggestion as to the age of the rocks becomes immensely helpful. If the age is in doubt the fact can be indicated by a question mark in the legend, but even a guess is helpful in suggesting the thought of one who has studied the territory more widely than is possible to one working against time to select the best locations in a given district.

There is apparently a growing sentiment against reconnoissance and general maps. This is unfortunate if the interests of the miner are to be taken into account. It is true that such maps must in the nature of things be not only incomplete but inaccurate. Yet they are the maps which in nearly every case are used in the development period of a mining camp, and in making them the geologist does the greatest service, quantitatively at least, to the mining industry that he is capable of. It is impossible to make an accurate and serviceable geologic map of a mining district, such as the maps of the Telluride and Butte folios of the United States Geological Survey, in advance of a certain amount of mining development. Such general maps, however, as are found in the Hayden *Atlas of Colorado* can be made readily and at comparatively low cost. They are at once avail-

able and serviceable. In the present oil development at Boulder, Colo., the Hayden map has been of the highest service. No doubt a more detailed map would be much better, but upon the Hayden base each oil expert can make a map of his own. If the investor were to wait until a proper map could be made by government or state officials, he would find the best territory all pre-empted and drilled.

So far, then, as helping in the development of new mining districts is concerned, it should be the first duty of the geologist to furnish good reconnoissance maps giving general data regarding (1) lithology, (2) structure, and (3) age. In spite of the limitations and inaccuracies of such maps their tremendous usefulness is sufficient warrant for their production.

I would not be understood as decrying the making of detailed maps. By no means. Let us have as many of such maps and as much detail as possible; but let us have first the reconnoissance maps and later, after the prospector and miner have developed a few good properties and opened up the ground enough to enable the geologist to get a right understanding of the structure and the ore bodies, let as detailed a map as possible be made. Such a map will be of the highest service in the development of a general plan of operation; the laying out of long cross-cut tunnels or the locating of deep shafts. Studies of the genesis of the ores made at the same time will indicate the probability as to the permanence of the ore bodies and give a reliable answer to the question of the erection of large permanent works, the building of railways, smelters. etc. In the beginning of mining operations these questions do not need to be answered. It is fortunately true that the initial operations are nearly always small and individual. It takes time to interest capital, to reconcile conflicting interests, and to bring about the economic conditions necessary to operations on a large scale. During the interval the general map is sufficient. There are no large works to be planned and it would be impossible to carry them out if there were. When, however, the

development of a camp has reached a stage where these questions arise, no map can be too detailed to be serviceable. In making such a map all available facts bearing on the original condition of the rocks and the subsequent changes they have undergone should be shown as far as possible.

H. FOSTER BAIN.

IDAHO SPRINGS, COL.,
February 17, 1902.

THE PHYSIOGRAPHIC FEATURES OF THE KLAMATH MOUNTAINS.

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Introduction.
General features.
- The chief ranges.
- Evidences of a peneplain.
- Valley depressions.
- Type of valleys.
- Deductions.

The larger basins.
The later sedimentary deposits.
- The Chico deposits.
- Neocene deposits.
- Lake systems of the Neocene.

Volcanic activity.
- The Cascade range.
- Lavas of the region.
- The Tuscan tuff.
- Faulting of the region.

Development of the present drainage.
Summary and conclusions.

INTRODUCTION.

THE Klamath Mountains were first recognized as a group deserving to be distinguished from other Coast Ranges and the Sierra Nevada when C. E. Dutton and J. S. Diller began their reconnaissance work in northern California and southern Oregon. It was first outlined in 1886 by Captain Dutton[1] as including all the mountains lying to the west of the upper Sacramento and Rogue River valleys, and probably other mountains of a similar age joining them on the north and south. The group was more definitely defined and characterized by Mr. Diller in 1892–93,[2] and their limits were extended southward beyond the fortieth parallel and northward to include the Rogue River Mountains, and some of the mountains of the upper Umpqua basin. According to Mr. Diller the name was first proposed by Major Powell many years earlier.

Geologically, the group of ranges now known as the Klamath Mountains resembles the Sierra Nevada in age and in the character of their formations, both igneous and sedimentary, though but little has yet been done to show their geological features,

[1] *Seventh Ann. Rept. U. S. Geol. Surv.*, pp. 97–103.

[2] *Fourteenth Ann. Rept. U. S. Geol. Surv.*, Pt. II, pp. 403–34.

except in their broader outlines. They embrace both sedimentary and igneous rocks, ranging in age from the Paleozoic to the Tertiary, though the later rocks form only a small portion of their mass and occur only in the larger valleys of the region. This group of mountains, which is clearly separated from the Sierra Nevada by the broad structural valley of the Sacramento, has been distinguished from the Coast Ranges to the north and south mainly upon geological hypotheses, it having been supposed that the ranges on either hand were of more recent origin, involving essentially younger strata. It yet remains to be shown, however, whether a satisfactory boundary can be so established, particularly upon the south. The metamorphic rocks of the Klamath system, including its schists and limestones, appear to be represented along the coast at intervals even as far south as San Francisco or even farther. The slates, cherts, and limestones of the Franciscan series, moreover, have their representatives among the Klamath Mountains and throughout the Coast Ranges.

GENERAL FEATURES.

The chief ranges.—The mountains included in the Klamath group have generally been regarded and described as a physiographic *complex*—a group of mountains without any definite order or relation, occupying a position at the junction of all the other systems in this portion of the coast. It is the purpose of this paper to call attention to a few of the more prominent facts pertaining to this question and to point out if possible some general system in their arrangement that has heretofore escaped notice. While it cannot be denied that the group holds in the main the position above described, it is believed that their disorder has been largely imagined. On the whole the group embraces a number of more or less independent ranges, some of which are much more prominent than others, some of them not having yet been distinguished by recognized names. They may be readily classed into two main systems which are believed to have a definite relation to the dynamical history of

the region, probably representing two or more periods of revolution.

The two systems of ranges cross each other nearly at right angles. The most conspicuous ranges, among which are the Rogue River, Siskiyou, Scott, and Trinity mountains, have a westerly, or south of westerly trend, while the Yallo Bally, Bally Choop, South Fork, and Salmon River Mountains, and many of the less important spurs and ridges approximate a more northerly or northwesterly course. The fold represented in the Salmon River range particularly can be followed from the Trinity basin nearly continuously northward to the Rogue River Mountains, crossing perhaps all of the ranges running toward the coast. Of the east and west ranges it should be noticed that while all of them apparently terminate in the vicinity of the Cascades, this termination, for two of them at least, is more apparent than real. The east and west axis, for example, that is represented by the Rogue River Mountains crosses the Cascade range near Mount Thielsen and continues in a north of easterly direction through eastern Oregon toward the equally old cluster of the Blue Mountains, and forms a broad though high divide between the drainage of the Klamath Lakes and the Deschutes and Crooked rivers, flowing toward the Columbia.

In a similar manner the high range traversing northern California in almost a parallel direction, along the southern border of Siskiyou county, has an eastern projection which crosses the Cascades in the vicinity of Mt. Shasta and forms a high divide which separates the drainage of the Klamath Lakes and river from that of Pitt River and the Sacramento. Midway between these two folds is the Siskiyou range, almost parallel to the others, but not traceable beyond the Cascades. On either side of the Siskiyou range are the valleys of Rogue River and the Klamath. Each of the three ranges contains old crystalline rocks, including granites, gabbros, and peridotites, whose age undoubtedly antedates the later Cretaceous rocks to be described presently. While it is not clear that these crystalline elements have any direct bearing upon the question, it cannot be denied

that these ranges represent axes of structural development that are very old compared to others that may be described.

Notwithstanding the fact that they have an east and west course, that has had a controlling influence upon the greater drainage, still it is not difficult to also recognize the north and south lines of folding traversing the country. South and west of the Trinity River the northwesterly direction of folding is shown by the course of all the larger streams. But even in the more central and most confused section of the Klamath group, that lying between the drainage basins of Rogue River and the Trinity, the north and south trend of the ranges impresses itself upon an observer, and the crossing of the ranges forms a magnificent spectacle for one who appreciates the larger features of mountain topography—and the influence of the factors controlling them is carried even into the smaller structural details of the country, regulating even the course of many smaller streams as well as that of dikes and auriferous veins.

Evidences of a peneplain.—Possibly to these facts is due in a measure the appearance in many portions of the group of a great uplift and dissected plain. Standing on any of the higher elevations of the country, say at an altitude of about five thousand feet, and looking over the surrounding mountains, one is often struck by the comparative uniformity of their outlines against the sky. From four to five thousand feet is for the most part their greatest altitude, and there are long ranges and ridges that stretch for miles at nearly a uniform level within these limits. One of the best examples of this fact is the South Fork range on the western boundary of Trinity county, which makes an even sky line for forty miles or more at an altitude above five thousand feet. The Siskiyous, the Yallo Bally, and Bally Choop ranges all furnish good examples of the same character. The general effect of this uniformity of level is that already suggested as a great uplifted and dissected peneplain that has been warped and diversified by differential movements subsequent to its development. South of the latitude of Cape Mendicino, Dr. Lawson has stated,[1] there is a broad peneplain that rises from a

[1] *Bull. Geol. Depart. Univ. Cal.*, Vol. I, pp. 242–44.

general elevation of 1,600 feet along the coast gradually toward the interior. Its eastern margin may be seen from the Sacramento valley, and, as viewed from the railroad, it has somewhat the effect of an escarpment that gradually rises toward the north. If the level effects of the mountains north of the Trinity basin are properly regarded as a peneplain, it is in a sense the northward continuation of the one described by Professor Lawson, and which rises gradually toward the north as well as toward the east. This approach to a peneplaination has been recognized by Mr. Diller,[1] and correlated with that represented in the

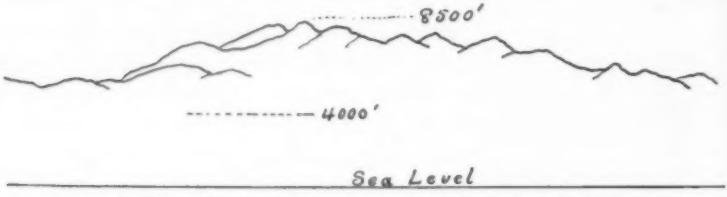


FIG. 1.—Profile view of the great Salmon mountain fold, south of the Klamath River.

broad western slope of the Sierra Nevada, which has been described as an inclined baselevel, the deformation of which took place at a comparatively late epoch. The great north and south fold already referred to rises above this level to an altitude generally of seven or eight thousand feet, as in like manner do also the Siskiyou, the Scott, and the New River ranges. The peneplain is distinctly noticeable along the coast in northern Humboldt and Del Norte counties, passing into Oregon, where it generally has an altitude between two thousand five hundred and four thousand feet.

The valley depressions.—All the larger valleys of the Klamath Mountain region are structural valleys. For the most part they may be included in two or three systems or basins, the significance of which has not yet been sufficiently recognized. One of these systems describes a broad curve across the northern portion of the Klamath Mountains, the other crosses them at the south.

[1] *Eighth Ann. Rept. U. S. Geol. Surv.*

As will be shown later, Shasta and Rogue River valleys are easily united, while the latter may be followed westward, toward and into a somewhat close connection with the valley of the Illinois River. On the other hand, the valleys of the Trinity basin may be linked together, connecting on the east with the valley of the Sacramento through a low divide between important ranges. Looking westward from the Sacramento valley in the neighborhood of Red Bluff one sees a low depression, separating what otherwise appears to be a continuous range of mountains bordering the Great Valley along the west. This depression is a low divide leading into the Trinity basin between the Yallo Bally and Bally Choop ranges. Beginning at this point a broadly curved line may be drawn in a northwesterly direction down the valley of a southern tributary of the Trinity, including the Hay Fork, Hyampom, South Fork, and Hoopa valleys, and extending to the mouth of the Klamath River. A little farther to the north a similar line may be drawn along the course of the main Trinity River, which merges into the former at the junction of the South Fork and the main branch of the Trinity. The two are included in what is here called the Trinity basin, which probably should be regarded as the southern limit of the Klamath Mountains, unless a purely geological or lithological basis of definition is to be employed, in which case they should be extended southward nearly, if not quite, to the Bay of San Francisco.

Type of valleys.—A peculiarity of all the intermontane valleys of the Klamath system is the manner of their drainage. Almost without exception their outlets cross one or more ranges through a narrow gorge or canyon. Shasta valley, for example, lying on the eastern flank of the older mountains, is drained, in common with the valley of the Klamath Lakes, by the Klamath River, which traverses a broad stretch of mountainous country to the westward for nearly one hundred miles before it emerges into the broader valley near its mouth. In its course it crosses the axis of the Salmon River range and other smaller ranges, through which its valley is reduced to the character of a gorge. And these valley-basins sometimes contrast rather

strongly with their drainage canyons. Scott valley, for example, lying entirely within the limits of the Klamath Mountains, has a nearly level bottom with general dimensions of eight by twenty-five miles, into which converges the drainage of more than twenty miles radius, yet the outflow from this valley goes through a canyon more than twenty miles in length, which is almost impracticable for a wagon road to follow. Indeed, in some places the walls of the canyon rise precipitously for more than a thousand feet. Most of the interior valleys are of this type, including the valley of the Hay Fork, Hyampom, Trinity, and Hoopa valleys, the Salmon River, the Illinois, and others.

Deductions.—The explanation of this interesting fact is that already suggested in a former paragraph. It is evidently a result of the cross-folding of the country—that is, to the development of folds transverse to the course of a drainage that had already been established. It is not maintained that this north and south system is entirely younger than the drainage, for this is not true, but it appears to be evident that there has been an uplifting of these transverse ranges after the drainage of the region had become established. The progress of this movement was not more rapid than the erosion of the streams in a downward and opposite direction. The transverse barriers are mainly north and south, or, to be more exact, a few degrees to the west of north.

These observations apply equally to the Trinity River, the Salmon River, the Klamath, and Rogue River, and, as has been said, to Scott River, the Illinois, and to some of their smaller tributaries.

THE LARGER BASINS.

The larger basins already outlined probably had their origin in the midst of, or prior to, the Cretaceous period. The Rogue River basin, while it does not topographically include the valley of Shasta River, yet in a geological sense it includes not only this, but also the valley of the Klamath Lakes as well. The Trinity basin has been already shown to extend from the upper Sacramento and to include the larger valleys tributary to the

Trinity River. Between these basins lies that of the Klamath and Salmon River drainage, the history of which has been only in part parallel to the others. The history of these basins can be best known from a study of their later sedimentary deposits.

THE LATER SEDIMENTARY DEPOSITS.

The later sedimentary deposits of these basins include only those of later Cretaceous and of Neocene ages.

The Chico deposits.—The Cretaceous deposits are largely those of the Chico, and consist of shales, sandstones and conglomerates, the lighter materials generally forming the lower portions of the series. As a rule they are fairly fossiliferous, and often extremely so. In their distribution the Cretaceous deposits occupy both of the basins above described, which appear to have been distinct and separate inlets from the sea. Although it has been the opinion of Mr. Diller[1] and others, including the writer, that the Cretaceous deposits of southern Oregon and the upper Sacramento valley have had a connection through what has been called "the Lassen Peak straits," the proof of such a connection has not yet been satisfactorily shown, and there is evidence in favor of a different conclusion. Mr. Diller himself has expressed a conviction[2] that many of the topographic features of the Klamath mountains have remained only partially modified since Cretaceous time. In this connection it is worth while remembering that the granitic and basic crystalline rocks of the Klamath Mountains are the counterparts of those in the Sierra Nevadas, but in the latter range they are generally conceded to have antedated the later Cretaceous. An axis of such rocks certainly extends eastward beyond Mount Shasta, and the probability is that the high divide between the drainage basins of the Pitt and Klamath rivers is of pre-Chico age, even including some of the older lava flows of Mount Shasta and the range to the eastward. This is rendered especially probable by the fact that the Chico beds almost on the western slope of Mount Shasta contain bowlders and pebbles

[1] *Eighth Ann. Rept. U. S. Geol. Surv.*, pp. 411–13.

[2] *Bull. Geol. Soc. Am.*, Vol. V.

of andesitic lava that could hardly have come from any other source. But one of the strongest evidences of disconnected basins during the later Cretaceous is found in a comparative study of the Chico faunas of southern Oregon and the Sacramento valley. The dissimilarity of these basins has been partially brought out by the writer in a former paper on the "Cretaceous Deposits of the Pacific Coast."[1]

The Cretaceous basin of southern Oregon represented in the deposits of Rogue River valley extended therefore southward to the foot of Mount Shasta and eastward, as shown by fossiliferous deposits, into the basin of the Klamath Lakes, and was perhaps bounded along the north, at least in part, by the older mountains of the Rogue River range. This basin connected with the ocean along the present course of Rogue River valley. In the basin of the Trinity River the later Cretaceous deposits occur, but whether the outlet of the basin was toward the Sacramento, or westward toward the ocean, has not yet been determined. But the Cretaceous deposits (probably the Chico) have a considerable distribution along the different tributaries of the Trinity, and the outlet may have been in both directions. Chico deposits have been found as far west as the Hay Fork valley, or even on some of the tributaries of the South Fork at an altitude that might easily connect them with the Pacific. Eighteen miles southwest of Hay Fork these deposits occur at an elevation of three thousand feet above sea level.

The Eocene period left no deposits in the Klamath Mountains, as restricted, that have yet been recognized, nor have they been discovered anywhere in the region between the Marysville Buttes and the valley of the Umpqua River. Throughout these basins, wherever the Neocene deposits occur, they rest nearly conformably on the Chico, or on the older basement rocks. The conformity of these beds upon the Chico is so marked that it is often difficult to distinguish them.

The Neocene deposits.— The Neocene deposits of these basins consist very largely of non-marine sediments, often plant bear-

[1] *Proc. Cal. Acad. Sci.*, 3d ser., Vol. II.

ing, and containing evidence of volcanic activity. Two members have been generally recognized, the Ione formation, and the Tuscan tuff. Mr. Diller states that the Ione formation on Little Cow Creek, Shasta county, has a thickness of five hundred feet and that to the east of this there is a great thickness of clays, sands and gravel which are sufficiently indurated to be called shales, sandstones, and conglomerates, and which he calls Ione. The lower half of the Ione formation on Little Cow Creek is composed chiefly of sandstones and shales, with a bed of coal and carbonaceous material twelve feet thick, with an abundance of fossil leaves.

In the basin of Shasta valley similar beds occur with plants and carbonaceous layers, and entirely similar deposits occur along the western slope of the Cascades in the Rogue River valley. These beds are best exposed a few miles to the east and to the north of Ashland, Ore. Four miles north of Ashland, where the series has been well exposed by faulting. they have a thickness of about three hundred feet. Similar deposits occur also throughout the Trinity basin, as at Weaverville, Big Bar, Hay Fork, and Hyampom. In the Hyampom valley, in western Trinity county, these beds are well exposed, and contain layers of coal and carbonaceous matter, and the leaves of many Neocene plants, including the Sequoia.

Lake systems of the Neocene.—As in the Cretaceous, so also during the Neocene period, the basin to the north of Mount Shasta appears to have been separated from the Sacramento and Trinity valleys. In the northern basin the Ione deposits form almost a continuous line from Shasta valley northward to Rogue River, or even farther. Regarding their extent eastward, there has been considerable conjecture. They have not yet been definitely traced beyond the summit of the Cascades; but this may be due to their being buried beneath volcanic eruptions. The Ione deposits are evidently those of fresh water, the period being one of extensive lakes lying to the south and east of the Klamath Mountains. In the Rogue River basin, which, as here used, includes the basin of the Klamath Lakes, it has yet to be

proved whether the beds occurring along the western slope of the Cascades should be regarded as the western margin of deposits underlying the Klamath Lakes, or belong to an independent body. It seems almost certain, however, that the basin of the Klamath Lakes must contain similar deposits, and that the Neocene drainage of the same basin was westward, and therefore that there was at least a connection with the deposits of Rogue River valley. Probably the connection was closer than one of mere drainage. But in any case it yet remains to be seen by which channel these waters reached the sea. If the outlet was by the present course of the Klamath, it must have traversed a mountainous country for at least one hundred miles, crossing masses of eruptive rocks like so many barricades, and the present dimensions of the canyon seem hardly proportional to the time and the volume of water that should have been discharged.

On the other hand, an alternative but little less difficult remains in supposing the outlet was through the Rogue River valley. Still, as we have said, the Rogue River valley is a structural depression dating at least from late Cretaceous time; and this fact lends a strong degree of probability for an outlet through this channel. Furthermore, the Cretaceous deposits of the Rogue River valley, as well as the older formations upon which they rest, show a broad line of terracing similar to that described by Mr. Diller in the upper Sacramento valley. This could only have been done in the presence of a body of water in post-Chico times, or by the reducing action of a large stream. It seems most probable, therefore, that the Neocene drainage of the upper Klamath basin was through the Rogue River valley, and that more recently it has been diverted to the present channel of the Klamath.

Overlying the Ione deposits, if there are such in the valley of the Klamath Lakes, are lake deposits apparently of a younger age. Possibly they may represent those of the Lahontan epoch described by Russell.[1] They consist for the most part of white diatomaceous and clayey beds extending far to the south, east,

[1] *Monograph XI, U. S. Geol. Surv.*, p. 143 *et. seq.*

and north of the present limits of the lakes, and aggregating a thickness of two to three hundred feet. They are occasionally, if not generally, interstratified with beds of volcanic sand and ash, and sometimes coarser material, and are often overlain by heavy beds of tuff, and in many cases by lava flows of quite local origin. These diatomaceous beds are accompanied by marginal terraces that plainly mark the former level of the water, probably at its maximum height. These terraces are especially observable in the vicinity of Klamath Falls and along Lost River and elsewhere, though they have been considerably disturbed by faulting and volcanic eruptions.

In the basin of the Trinity River, upon the southern border of the Klamath Mountains, Neocene deposits occur that Mr. Diller no doubt correctly correlates with the Ione of the Sacramento.[1] Here, as in the Rogue River basin, they have nearly a conformable relation to the Cretaceous deposits wherever they are found in contact, and they have not yet been satisfactorily distinguished from each other.

VOLCANIC ACTIVITY.

The Cascade range.—There has been more or less discussion at different times regarding the character and age of the Cascade range. It is now generally conceded to be pre-eminently volcanic in character, but as to its age there is less agreement. There can hardly be any doubt, however, that the Cascade range as a mass of volcanic rocks, is the northward continuation of the volcanic elements of the Sierra Nevada, and that it contains representatives of the lava flows that have covered so much of the Great Basin.

Lavas of the region.—J. E. Spurr has recently summarized some of the facts already known[2] relating to the age and succession of lavas in the Sierra Nevada and the Great Basin. It is apparent that the volcanic activity of this region has extended over long periods of time, beginning at least with the early Tertiary (Eocene) and continuing to the present. It is therefore

[1] *Fourteenth Ann. Rept. U. S. Geol. Surv.*, Pt. II, p. 419.

[2] JOUR. GEOL., Vol. VIII, No. 7, 1900, pp. 621—.

probable that the Cascade range is an accumulation of volcanic materials of as many different epochs. In many places, as near the Klamath River, this succession of periods, as well as the succession of minor flows, is well illustrated. At the head of the Little Shasta River, no less than four epochs are represented by as many different effusions. Dutton recognized the same long duration of volcanic activity in the Cascades of southern Oregon stating that it probably prevailed throughout nearly the whole of the Tertiary.[1]

The Tuscan tuff.—One of the later periods of volcanic activity is represented by what has been called the *Tuscan tuff.* This consists of a series of volcanic fragmental material, sometimes stratified and sometimes without stratification. It has a wide distribution in the upper Sacramento valley, where it has been described and mapped by Mr. Diller.[2] The volcanic tuffs of the Cascades north of Mt. Shasta, as well as the Ione and the Chico, demonstrate the secular accumulation of the lavas forming the range. As a rule the tuffs are interstratified with lava flows of somewhat different characters, some of which are older and some younger than the tuffs. Rhyolitic and andesitic tuffs have a wide distribution to the east of the Cascade Mountains, occurring abundantly in the basin of the Klamath Lakes, where they overlie, for the most part, the diatomaceous deposits as already stated. They also form thick deposits in the region of Silver and Summer lakes.

Faulting of the region.—A large amount of faulting has taken place subsequent to the distribution of these tuffs, often leaving them exposed in conspicuous cliffs. These fault lines, in so far as they occur in the region of the Klamath Mountains, are only outlying members of the great system of faulting traversing northern Nevada and southeastern Oregon, and which have been described by King,[3] Russell,[4] and others.[5]

[1] *Seventh Ann. Rept. Geol. Surv.*, pp. 100–1.

[2] *Eighth Ann. Rept. U. S. Geol. Surv.*, Pt. I, pp. 422–24.

[3] *Fortieth Parallel Repts.*, Vol. I, 1878, p. 735 *et seq.*

[4] *Monograph XI, U. S. Geol. Surv.*, 1885, p. 26 *et seq.*

[5] *Proc. Cal. Acad. Sci.*, 3d ser., Vol. I, p. 262 *et seq.*

Contemporaneous Neocene deposits are now found at all elevations in the Klamath Mountains, up to four thousand feet, and in such relations that it is clear that differential elevation of the region has occurred since their deposition. Probably some of these disturbances were coincident in time with the faulting that has been described as occurring in the Great Basin. In the interior of the Klamath group, faulting on a scale comparable to that of the Great Basin has not yet been clearly recognized, though many minor faults occur that perhaps coincide in time. Sharp flexures, as that along the western border of Scott valley, occur, some of which may be traced for many miles, but there are no well established extensive fault lines.

DEVELOPMENT OF THE PRESENT DRAINAGE.

During middle or late Neocene times there existed among the Klamath Mountains and along their southern and eastern borders extensive series or systems of lakes that have left their deposits in unmistakable evidence. These deposits rest conformably upon those of later Cretaceous, in such a manner that they have not always been distinguished.

During the period which intervened between the deposition of these two series of strata—the Eocene—we are left to infer that there was unrestrained erosion and aereal reduction throughout the region, covering indeed the long interval between the close of the Chico and the opening of the Ione, to the effects of which those of the Ione itself were added. Whatever traces there may be, therefore, of an ancient peneplain in the Klamath Mountains, it must doubtless be in part referred to this time. The fact should be emphasized that the drainage of the Klamath Mountains is westward, and it has probably remained so since Cretaceous time. There is no drainage that can properly be called eastward from these mountains, while the streams leading to the west derive their waters even from the eastern limits of the group, and probably during the Neocene period it was much the same. The canyons, or river channels of the period had been developed approximately to their present length and are fairly

represented in those of the present, except as to depth. The canyon of the Klamath had retreated nearly to the drainage of the Klamath Lakes, and was possibly separated from it by only a low divide. As to the causes which led the drainage of the Klamath Lakes from Rogue River to the present outlet, it is not quite clear whether it was by the choking of the Rogue River outlet by later lavas, or by faulting, or by both combined. To the north of the Klamath River there is evidence of considerable faulting along the western slope of the Cascades, the upthrow of which could have cut off the outlet from the lakes in the direction of Rogue River, while in the vicinity of the Klamath no great amount of faulting has been observed, but on the contrary there is a depression of the Ione and Tuscan deposits. Furthermore, the Klamath River cuts these deposits in such a manner as to harmonize with this view.

SUMMARY AND CONCLUSIONS.

The physiographic features of the Klamath Mountains are in general those of crossing ranges and intervening structural valleys, modified to a considerable extent by the effects of ordinary river erosion. Evidences of an elevated peneplain are unmistakable at an altitude of four or five thousand feet above sea level. This peneplain is to be referred in part to degradation during the Cretaceous period, and in part to such action during the Tertiary. This peneplain has been subjected to disturbances ranging in time from inter-Cretaceous to the present. The earlier differential movements were those which originated the structural features that are conspicuous at present. The later movements have developed folds with north and south axes, the evidences of which are many. The principal north and south fold coincides with the Salmon River range, seen to the west of Scott valley, and its continuation on the north and south toward the Rogue River Mountains and the Trinity basin. It crosses all of the principal rivers of the region in a manner that demonstrates its secondary age, which was probably in part comparatively recent. The streams have maintained their westward

course across this fold developing in nearly every case deep and narrow canyons, and proving its gradual elevation. The result of this action is a type of valley peculiar to this region, namely, that of valleys entirely inclosed by mountains and drained through deep narrow canyons. The larger basins of the Klamath Mountains include the Rogue River basin and that of the Trinity River. Both contain upper Cretaceous and Neocene deposits, almost or quite conformable, overlain by beds of volcanic tuff or lavas. During both of these periods the valley of the Klamath Lakes was connected with the Rogue River drainage, which condition extended into the latest Tertiary times.

The lake systems of the Neocene were two, that of the upper Rogue River (Klamath) basin, and that of the Trinity basin. Throughout the Tertiary, volcanic eruptions were in progress, and following this period occurred some of the later flows of lava and the formation of beds of volcanic tuff throughout the Cascade range and eastward. The latest flows accompanied by more or less faulting diverted the drainage of the Klamath Lakes from the Rogue River to the Klamath, and accompanying movements in a similar manner disturbed the drainage in other portions of the Klamath Mountains.

F. M. ANDERSON.

BERKELEY, CAL.,
1901.

BOSTON MOUNTAIN PHYSIOGRAPHY.

UPON a careful perusal of Professor A. H. Purdue's recent article on the "Physiography of the Boston Mountains, Arkansas,"[1] it will appear that he dissents from the opinion that there is represented in the summit of that range a plain of denudation older than that which is usually supposed to be widely developed over the Ozark plateau north from the Boston Mountain; and this interpretation he bases upon comparison of the erosion forms characterizing the two areas, finding that the lower and heretofore supposedly "newer" region (considered from the standpoint of the physiographer), in reality has by far the older type of topography. It seems to the present writer that Professor Purdue has overvalued some of the evidence and minimized or totally ignored other factors which may have an important bearing on the question at issue.

Ever since my paper on the "Peneplains of the Ozark Highland"[2] left my hands I have been conscious of a slight discrepancy in my interpretation of the topographic development of west-central Arkansas, and I wish to take advantage of this opportunity to set it aright.

In identifying the truncated summit of the Boston Mountain as a remnant of the same supposed dissected "Cretaceous" peneplain, as is indicated in the summits of the Ouachita ranges south of the Arkansas river, I dwelt too strongly on the general correspondence in height of the two systems of ridges, and later vitiated the conclusion based thereon by developing the probability that the present elevated condition of the Boston Mountain region is largely due to differential uplift in the early part of the Quaternary era.

Dr. C. R. Keyes, in his article on the "Composite Genesis of the Arkansas Valley Through the Ozark Highlands,"[3] seems to

[1] JOUR. GEOL., Vol. IX, No. 8, p. 694.

[2] *American Geologist*, January, 1901, p. 21. [3] JOUR. GEOL., Vol. IX, No. 6, p. 486.

appreciate the true significance of the evidence, and the figure which he gives on p. 487 is virtually in accord with my present conception of the subject. It is believed (for the same reason that a dissected peneplain is recognized in the summits of the Appalachian ridges) that the summits of the Ouachita mountains are remnants of an old plain of denudation (whether in age Cretaceous or early Tertiary matters not), and that this plain would descend rapidly to the axis of the Arkansas valley had it not been totally destroyed over that broad structural and topographic depression; and that then it would rise northward because of a monoclinal folding inaugurated in early Quaternary time, and perhaps continuing today. The question is, Would this projected plane coincide with the summit of the Boston Mountain?

Let us eliminate later deformation and straighten out the supposed lower or "main Tertiary" plane of erosion baselevel. Our theory supposes that the earlier or "Cretaceous" baselevel plane would first become distinctly differentiated from the later in southern Missouri, and the difference between them would have increased to about five hundred feet on the northern edge of Boston Mountain. Continued to the first ridge of the Ouachita system, the difference between the two planes might be expected to be one thousand feet, but through the concavity common to the border of all symmetrical dome-like uplifts it would be natural to expect an increase to at least the present difference in level of the planes at the summit and base of Sugar Loaf Mountain, about 1200 feet, I believe.

But Professor Purdue has raised a question of the validity of this interpretation by his erosion studies, the pertinence of which cannot be ignored. He says, in reference to the Boston Mountain region:

> The drainage of the region is that intermediate between youth and maturity. The streams are vigorous and have completely dissected the plateau by the formation of gorges from 500 to 1000 feet deep, thus producing a very rugged topography over the whole region. Between these gorges the slopes often meet, forming more or less rounded hills; but more frequently

the intervening area is occupied by flat-topped, sandstone-capped hills of limited extent.

Of the lower plain to the north, he says:

> This is a region of great denudation. . . . . Its streams are mature, the valleys comparatively wide, and the topography in general presents the aspect of much greater age than that of the Boston Mountains.

"Youth" and "maturity" as applied to streams and valleys are terms relating to types and not to age as measured in years. The topography and drainage of a land never greatly elevated, and possessed of a humid climate and soft formations may be ever so senile in type and yet no older in years occupied in its development than another region characterized by immaturity of its physiographic features. This is an axiom of the science of physiography. The less mature character of the drainage and erosion forms of the Boston Mountain region than of that on the north does not necessarily militate against a reference of the development of its summit plain to an earlier cycle of erosion.

Some of the causes which have tended to bring about this result are as follows:

Boston Mountain owes its prominence and preservation as a residual on the "main Tertiary" peneplain largely to the resistant properties of the Upper Carboniferous sandstone which enters so largely into its composition. On the south, the Arkansas valley was developed on a belt of soft shales and all traces of residuals were swept away. On the north, the elevation of the land was less, the streams soon cut down to baselevel and could devote a large part of the cycle of erosion to widening their valleys. The Boston Mountain was on the main divide between the White and Arkansas river systems, and only very small streams operated on it while the country on either hand was being ground away by powerful trunk streams. The latter developed meandering courses indicating maturity, but we could hardly expect to find similar winding courses in the small headwater streams of the main divide.

The evidence of youth in the Boston Mountain valleys is somewhat deceptive, especially on the southern slope. Here I

recognize valleys of several cycles trenched beneath each other and coalescing so as to be apparently the product of a single cycle of erosion. (I am using the term "cycle" as referring to the time between uplifts with rejuvenations of the drainage.) Eliminate all those portions of the valleys which are below the supposed "main Tertiary" baselevei plane, say five hundred feet below the general summit level of the mountain, and much of the youthfulness will disappear; the valleys remaining will be comparatively broad and flat-bottomed.

Another indication of immaturity recognized is the flat summits. This feature is maintained by the rather resistant sandstone strata capping the hills and its importance is exaggerated by its abnormal character.

If the summit plain of the Boston Mountain was not developed anterior to that of the lower county on the north, it must have been elevated by faulting. The northern face of the Boston Mountain is "an irregular, but bold escarpment from five hundred to one thousand feet high." This is entirely too sinuous to be a degraded fault scarp. Great promontories project out into the plain country on the north. The phenomena are characteristically those of differential erosion. If a fault with a throw of five hundred or one thousand feet existed, it must have dislocated the Upper Carboniferous sandstone in such a conspicuous manner as would long since have attracted attention. In short, I cannot see any escape from the conclusion that the Boston Mountain was a residual on the baselevel represented by the plain to the north—the Ozark plateau.

The criteria on which I would base the recognition of a dissected peneplain on the nearly horizontal rocks of the central Mississippi region are: (1) many of the summits must be truncated; (2) these flat summits must fall into a single plane, only very slightly tilted; (3) the plane must pass across diverse formations without deformation; (4) the plane must to some extent bevel the edges of the slightly inclined strata; and (5) the dissected plain must be extensive enough to make it improbable that it was developed by marine erosion. Such other

phenomena as meandering stream courses and monadnocks are valuable adjuncts, but not essentials. How do these principles apply to the Boston Mountain region?

In arriving at the most natural explanation of the uniformity in height of the Boston ridges, six hypotheses may be briefly examined: (1) That it is a plain of aggradation of Upper Carboniferous age which remained intact until very late geologic time because of having stood virtually at sea level. This is calling into play a possibility which is not a probability. From what is known of the history of the continent in post-Carboniferous time, it may be considered unnatural. However, even allowing that such a strange coincidence may have occurred, I should still claim the summit plane of Boston Mountain as representing a baselevel of subaerial erosion, an appendage to a true peneplain. (2) That it was planed off by marine erosion and a thin sheet of Cretaceous or Tertiary sediments deposited on it. A submarine shelf, twenty miles in width, would have a considerable thickness of sediment resting on its seaward portion, and some remnants should remain on the flat-topped hills. If the submergence was very short, I should claim the reduction of the area to a plain condition to have been virtually the work of subaerial denudation, very slightly aided by marine action. As a matter of fact, there is no collateral evidence of such submergence in post-Carboniferous time and the drainage system is against it. (3) That the uniformity in height of the separate ridges which together constitute the Boston Mountain can be attributed to the intersection of the slopes of valleys having a common baselevel is an untenable position because most of the ridges have truncated summits. (4) The conditions of the soil, climate and amplitude of elevations are not such as to give value to any argument based on differential protection by vegetation. (5) That it is a structural plain resulting from the unequal resistant properties of the Carboniferous strata eroded. This implies that there be strict parallelism between the plain and the bedding of the rocks, for studies in the western states where this agency has had full play in the production of topographic forms, make

it certain that there must be no general beveling of hard and soft layers. Professor Purdue says:

> Structurally, in the western part of Arkansas, these mountains are a broad flat anticline, the strike of which is east and west. According to the geologists of the Arkansas Geological Survey, it appears that the extreme eastern part of the region is monoclinal in structure with the dip to the south.

The dissected plain is also slightly tilted and slightly bowed, but I invite someone to show that it is strictly parallel to the structure. Specific data on this point are wanting. I believe that the plain actually bevels the slightly inclined strata, and if the summit-plane of the outliers on the north be admitted into the argument, I know that it does. (6) By elimination, the peneplain hypothesis comes to the front as that which furnishes the most natural explanation of the phenomena observed and violates no established principles of physiography. I believe the peneplain character of Boston Mountain is as firmly established as that of any other recognized dissected peneplain in eastern America. It is not proved and perhaps never will be as proof is made in other departments of science. A strong suspicion now existing that an ancient peneplain is represented may be strengthened as more precise data are recorded and in time the critics may cease opposition. At present their activity is desirable as stimulating the collection of evidence.

As precedents for disregarding, in the conclusion that the dissected plain at the summit of Boston Mountain has an age greater than that of the "main Tertiary" peneplain, the argument drawn by Professor Purdue from the contrast in stage of maturity of drainage and topography on the two areas, I will mention the plateau of West Virginia with its narrow valleys, standing as a residual on a Tertiary baselevel which in other portions of the Appalachian region has broad basins and mature topography; and the Niagara plateau of northeastern Iowa, rising prominently above a lower dissected plain whose valleys are equally as large.

OSCAR H. HERSHEY.

BERKELEY, CAL.,
Jan. 21, 1902.

DRAINAGE OF SOUTHERN INDIANA.

INTRODUCTION.

Area to be discussed.—Only those features of the drainage of southern Indiana which are dependent upon geological structure and are not controlled primarily by glacial drift will be discussed. This limits the discussion to that portion of the state that lies south of a line running from Indianapolis east to the Ohio state line, and from Indianapolis southwestward along the course of West White River to the mouth of that stream.

While the eastern tributaries of the West White River from Indianapolis to the mouth of Bean Blossom Creek, and the tributaries of East White River in northern Shelby and Johnson counties, owe their positions largely or entirely to the drift,[1] the main streams of the area referred to are controlled by the underlying strata.

The driftless and drift-covered regions.—The driftless region of southern Indiana is an irregularly triangular area, with the base of the triangle along the Ohio river, reaching from Mount Vernon to a point a few miles above Jeffersonville, a direct distance of 135 miles, and the apex of the triangle near the northeast corner of Monroe county, 135 miles northeast of Mount Vernon and 85 miles slightly west of north from Jeffersonville. All other portions of the area under discussion are, or have been, more or less covered by the drift.

Over most of the region both directly east and directly west from the unglaciated area the covering of drift is comparatively thin. In the region to the east especially, the drift covering is rarely as much as 100 feet thick, and many of the streams have cut down through it and into the underlying rocks. In some cases these streams occupy preglacial channels; in others the

[1] These small streams are not included in the following remarks regarding the drainage. Neither are the streams between West White and Wabash rivers discussed, although those streams are shown on the map, Plate VI.

valleys have been cut out entirely since glacial times, leaving the drift in remnants only upon the hilltops and uplands.

Effect of the structure in the region thinly covered by the drift.— The thin mantle of drift that covers that portion of the state east of the driftless area lies on strata that dip gently to the southwest, and on an old surface whose general contour prior to the deposition of the drift was similar to that of the present time. Therefore, while the minor lines of drainage have been modified by the drift, the general south and southwest drainage of the country is such as would be logically developed in a country of such combinations of hard and soft southwestward dipping strata as southern Indiana possesses, and it is practically the same now as it was in preglacial times.

The series of strata that control the topography and drainage.— There are in southern Indiana three thick series of shale beds, between which are groups of harder and more resisting limestones and sandstones. In going from east to west across the state these groups are as follows: (See the numbers on the cross sections shown on the accompanying drainage map, Plate I.) (1) the Hudson River shales, along the east side of the state; (2) the resisting Niagara limestone, and limestones at the base of the Devonian; (3) the New Albany and Knobstone shales, all soft and easily eroded beds; (4) the Knobstone sandstones and overlying Carboniferous limestones, which are in turn overlain by the sandstones at the base of the Coal-measures;[1] (5) the soft Coal-measures, shales, and sandstones of the west side of the state.

Postglacial and preglacial topography.—The softer groups of strata, viz., 1, 3, and 5, form drainage areas (discussed below as the eastern, central, and western drainage areas respectively) that are more or less separate from each other in each case, while the harder groups, 2 and 4, form the highlands or watersheds between those areas.

[1] The Lower Carboniferous limestones are eroded more easily than the beds lying both east and west of them, but their denudation has not been so great as to form a separate drainage basin in the area underlain by them.

The strata that form the different drainage areas and the watersheds between them in the southern part of the state extend northward under the glacial mantle for some distance beyond the boundary of the accompanying map (Plate I). Therefore it might be expected that the preglacial relief of the country underlaid by those strata was similar to the present relief in the unglaciated area to the south, and this is found to be the case.

The effect of the highlands (formed by groups 2 and 4) where they plow northward under the glacial mantle and lift it up, is noticeable for many miles north of the southern limit of the drift. These buried highlands show that the preglacial topography of the region thus affected was similar in general lines with the present topography which is almost, or entirely, unaffected by the drift at the southern part of the state. Well records show that the central drainage area, or trough, and its eastern rim extended as far north in preglacial time as the north side of Clinton county at least, while the highlands west of it certainly extended as far north as northern Montgomery county.

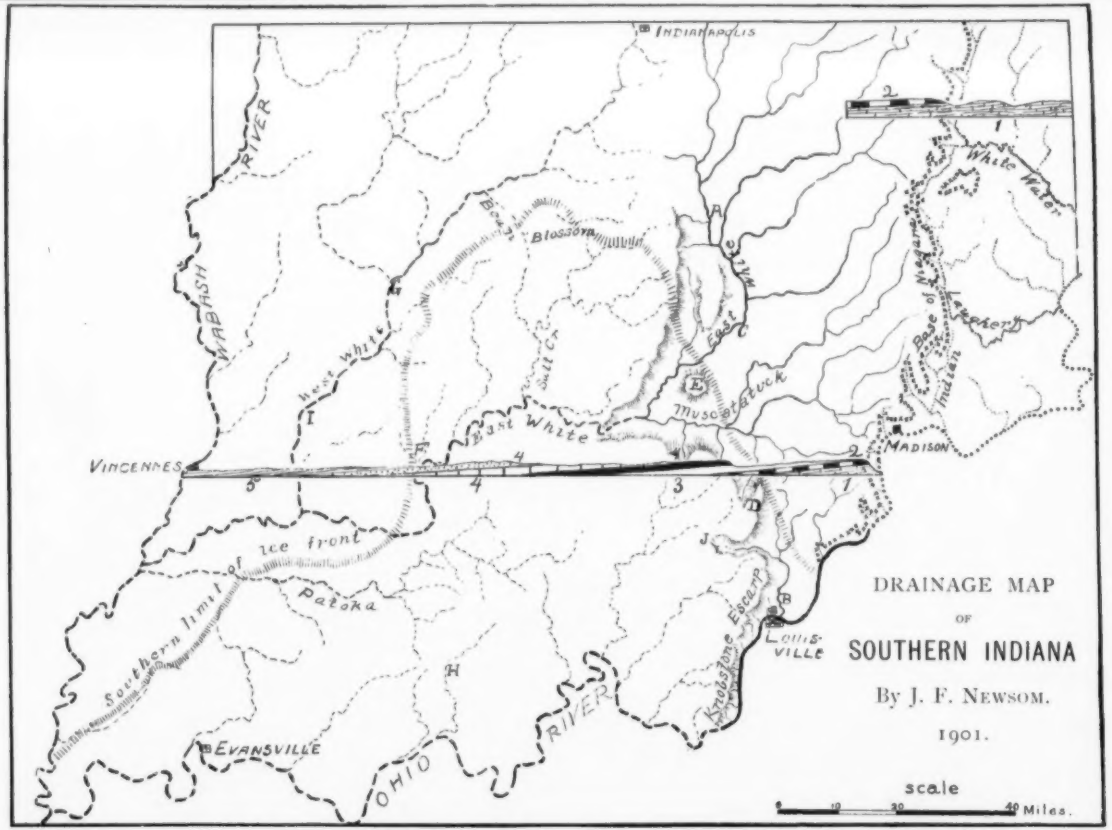
The preglacial topography makes it seem quite probable that the preglacial drainage of this trough was from the eastern rim down the dip of the underlying limestones to the southwest, along lines generally parallel with those of the present streams further south, which are in accordance with, and are controlled by, the geologic structure.

The relations of the different drainage areas and the structure controlling them is shown by the cross sections on the drainage map, Plate VI.

It will be seen, therefore, that the drainage of southern Indiana may be treated in accordance with the groups of strata that control the topography of the region.

Relations of the structure to the drainage.—An examination of the geology in its relation to the drainage shows that there are the three following general drainage areas:[1] (1) the eastern area, covered by rocks of the Hudson River group, and including

[1] These areas cannot be regarded as basins in the proper sense of the term, for each area is drained by many different streams.



Drainage Map of Southern Indiana. The streams of the eastern drainage area are shown by dotted lines, those of the central drainage area are shown by solid lines, and those of the western drainage area are shown by broken lines. (Glacial boundary after Leverett.)

ON CROSS SECTIONS: 5 = Coal-Meas. shales. 4 = Mansfield s's't. / Low. Carb. l's't. / Knobstone s's't. 3 = Knobstone shale. / Devonian shale. 2 = Devonian l's't. / Niagara l's't. 1 = Hudson River shales.

some short streams that rise on the Niagara strata and flow eastward into the Hudson River area; streams of this area are shown by dotted lines on the accompanying map, Plate VI; (2) the central area, covered by the strata between the base of the Niagara and the Knobstone sandstone; streams of this area are shown by solid lines on the accompanying map, Plate VI; (3) the western area, covered by the rocks from the Knobstone sandstone to the top of the Coal-measures; streams of this area are shown by broken lines on the accompanying map, Plate VI. This last area includes the entire southwestern part of the state, and in the eastern part of it the streams have in many places cut down through the limestones and Knobstone sandstones, and into the Knobstone shales. These shales, however, have had no part in the formation of the western drainage area, which, while largely underlain by sandstones and limestones, has its eastern watershed along the Knobstone escarpment within a few miles of the lowest part of the central area.

From each of the watersheds, viz., between the eastern and central, and the central and western areas, the streams that flow east across the dip of the strata are short and have steep gradients, while those that flow west with the dip of the strata, are long and have low gradients.

The larger streams of southern Indiana flow through filled valleys. The depth to which the valleys have been filled varies from a few feet to over one hundred feet.

The different drainage areas will be taken up in their order, and the features of their drainage so far as these depend upon the structure of the underlying rocks will be pointed out. The boundaries between these areas do not follow exactly the outcrops of the strata which form the divides between them, for short streams which belong to the area underlain by Hudson River beds, for example, may rise in the Niagara beds and flow eastward across the dip of those beds for a short distance before entering the area of the Hudson River strata. The same is true of streams belonging to the central basin, which rise at the top of the Knobstone escarpment. On the other hand, the streams

flowing westward sometimes cut down through the hard strata that form the watershed, exposing the underlying softer strata. These facts must be kept in mind in treating the general drainage areas in accordance with the underlying strata.

THE EASTERN DRAINAGE AREA.

While the highest points in the eastern area are almost as high as the watershed at its western side, the streams of this area have cut out valleys from one hundred to four hundred feet deep in the soft Hudson River strata, and the average level of the country is therefore considerably lower than that of the country immediately west. The Hudson River strata are almost horizontal, and with few exceptions the streams flow more or less directly to the Ohio River.

Attention should be called, however, to the upper courses of the Whitewater River,[1] Laughery Creek, and Indian Creek.

The upper courses of these streams are almost in line, they flow nearly due south, parallel with the watershed formed by the Niagara strata, and only a few miles east of that watershed.[2] Excepting those of Indian Creek, the tributaries of these streams that enter from the east and north are comparatively long, while those from the west which rise in the Niagara strata and flow eastward across the dip are short. The main drainage lines and their relations to the controlling beds to the west are shown on Plate VI.

Indian Creek, which drains portions of Ripley and Jefferson counties, flows southward parallel with the watershed at the west, but owing to its shortness and its proximity to the Ohio, this is the course that would be expected of it regardless of the dips of the rocks of the area. It should be noted also that when the Ohio strikes the region of outcropping Niagara limestone at Madison it makes an abrupt turn to the south, and flows south

[1] Whitewater River flows through a preglacial valley below Connersville (Leverett).

[2] It seems probable that these streams have been shifted to these positions by the westward inclination of the beds, although this inclination is very slight.

for about eighteen miles before turning to the southwest and cutting through the Niagara strata.

It is seen, from what has been said above, that the area covered by the Hudson River strata has its main drainage lines parallel with its western rim; that for the most part there are southward flowing streams in the area immediately east of and practically all along this rim, that the tributaries from the west are short, while those from the east are long, and that these features of the erosion may be due to the gentle westward inclination of the strata at the west edge of the area. As the streams approach the Ohio their relations to the watershed at the west are lost, as is seen by the abrupt eastward turn of the Whitewater in northeast Franklin county, and of Laughery Creek in southeast Ripley county.

THE CENTRAL DRAINAGE AREA.

The central drainage area has its eastern watershed formed by the Niagara and Devonian limestones, while its western watershed is formed by the Knobstone sandstones and overlying limestones that form the crests of the hills known as the Knobs.

The east-west profile of this area and its geological relations are shown on that portion of the cross section (Plate I) extending from the Niagara strata to the Knobstone sandstones. The east side of the basin has a gentle slope to the west, while the west side has a steep slope to the east.

The shape of the central drainage area is shown on Plate I, where its streams are shown by solid lines. This area is about fifty-five miles across in its widest part at the north and narrows down until it is less than a mile wide along the Ohio river at the south.

On Plate VI this trough, the axis of which extends from near Edinburg (*A*, Plate VI) slightly east of south to the Ohio River near New Albany (*B*), is shown. From Edinburg to the Ohio the axis is followed approximately by the line of the Jeffersonville, Madison & Indianapolis railroad. The central area, in which the control of the structure upon the drainage is more clearly marked than in either the eastern or western areas, is

made up of two districts: a southern district from which the streams flow directly into the Ohio River, and a northern district, drained by East White River and its tributaries into the Wabash.

The southern district.—After cutting through the Niagara and Devonian limestones the Ohio River flows west and southwest across the southern district until it reaches the strata of the Knobstone group west of New Albany. Here it is deflected to the south and runs close under the bluffs formed by the Knobstone standstone and overlying limestones for about eighteen miles to Taylor township, Harrison county, where it turns to the west and cuts through the Knobstone sandstones and overlying limestones. The southern deflection of the Ohio west of New Albany is very similar to its southern deflection by the Niagara and Devonian limestones just west of Madison. The valley of the Ohio is wider where it crosses the central area, in the neighborhood of New Albany and Louisville, than it is either immediately above or below that locality. This widening of the valley is due to the character and relations of the strata crossed, and in no way indicates that the former size or course of the stream differed greatly from its present size and course. Neither does it indicate that the present river valley at this locality crosses the wide north-south valley of a former large stream.

The streams that enter the Ohio from the west below New Albany are short and have steep gradients. Most of these streams have noticeable down-stream deflections where they enter the Ohio bottom lands, their mouths having been shifted down stream by the deposition of sediments on their up-stream sides.

Above New Albany, Silver, and Fourteen Mile creeks are the principal streams. Silver Creek rises in the Knobstone hills at the south side of Scott county and flows almost due south until it reaches the Ohio above New Albany (*B*). Muddy Fork, one of the tributaries of Silver Creek, rises well over in the Knobstone area near the west edge of Clark county and flows eastward for fifteen miles, across the dip of the strata, before entering the main stream and turning south to the Ohio.

Fourteen Mile Creek rises in the southwestern part of Jefferson county, flows slightly west of south with the dip of the strata and enters the Ohio three miles southeast of Charleston. In its lower portion Fourteen Mile Creek cuts down into the Hudson river strata. Other shorter streams have their sources in the area covered by the Niagara limestones, or the Devonian strata, and flow more or less directly into the Ohio across Hudson river strata. While the general courses of these streams are such as might be expected from the structure of the underlying strata (with the exception perhaps of Muddy Fork of Silver Creek, which rises at *P*, Plate VI, and flows eastward across the dip of the Knobstone strata), the influence of that structure on them is by no means so clearly marked as it is on the streams in the district next to be considered.

The northern district.—It is in the northern district (that portion of the central area lying north of the southernmost cross section, Plate VI), drained by the East White and Muscatatuck rivers, that the effect of the structure upon the drainage is most clearly seen.

The streams that drain the northern district rise for the most part near the watershed which separates this from the eastern drainage area, within a few miles of the main drainage lines of the eastern area, and flow westward down the gentle slope that owes its inclination to the dip of the underlying beds. In their upper portions most of the streams have gradients greater than the dip of the underlying beds and have consequently cut down from newer into older strata. In their lower courses the gradients are less than the inclination of the strata, and the streams pass across successively newer beds.[1] The streams that rise on the western rim of the northern district and flow eastward are short and have steep gradients.

Except for the course of East White River below Seymour

[1] This feature is well shown by the tributaries of Stucker's Fork, in townships 3 north, 8 and 9 east. These streams rise in the Devonian shale area, flow westward with the dip, but cut down through the shale, exposing the underlying limestones for a distance of about six miles, and then, the fall becoming less than the dip of the underlying beds, again pass out into the shale area.

(with which is included the lower course of the Muscatatuck), the drainage lines of the central area are evidently controlled by the geological structure of the country. The effect of the structure upon these streams is well shown in the case of Ramsey Creek — a tributary of the Muscatatuck — which rises just west of Madison near the northeast corner of township 3 north, 9 east, within one and one-half miles of the Ohio River, and 360 feet above that stream. The waters of Ramsey Creek flow into the Muscatatuck, then through East and West White rivers, and the lower Wabash, and finally empty into the Ohio at the extreme southwestern corner of the state, a direct distance of 170 miles from the source which was within one and one-half miles of the Ohio.

From Edinburg to Rockford, a distance of twenty-seven miles, East White River flows southward, parallel to the Knobstone hills and but a few miles east of them. Its tributaries from the west are short and have steep gradients. Those from the east and northeast are long. They rise at the watershed formed by the Niagara strata and flow with the dip down the southwestward slope of the country. The sources of some of the eastern tributaries of East White River are but a few miles west of the Whitewater River — the main drainage stream of the eastern area. The asymmetry of the area drained by East White River is shown by the accompanying drainage map (Plate VI).

One of the most interesting features of the drainage of the central area is the course of East White River below Rockford (*C*, Plate VI). From Edinburg to Rockford this stream flows south along the bottom of the trough east of the Knobstone hills. But while this trough extends on southward to the Ohio River and is apparently the line along which White River could have most easily developed its course, that stream, instead of following the valley (*A*, *C*, *B*, Plate VI) to the Ohio, turns to the west at Rockford and flows through broad bottom lands until it is joined by the Muscatatuck, at the south side of Jackson county. Just below the mouth of the Muscatatuck it enters a comparatively narrow valley, which has been cut down through the Knob-

stone strata, the overlying Lower Carboniferous limestones and the Mansfield sandstone. This valley varies in depth from less than fifty to over two hundred and fifty feet; its length is about seventy-five miles. In width the bottom of the valley (which is filled with alluvium from fifty to seventy-five feet or more), varies from one-half mile to over one mile.

Thus it is seen that instead of carving out a valley along the strike of easily eroded strata, southward from Rockford directly to the Ohio, a distance of fifty miles, East White River turns to the west, flows through a valley cut across hard strata, and finally reaches the Ohio through the Wabash at a point over 150 miles from Rockford.

Two hypotheses may be advanced in explanation of the course of East White River below Rockford.

The first is that the present is approximately the original course of the river; that as this region was first elevated the drainage from the land at the east was deflected to the south parallel with the Knobstone sandstones and behind (*i. e.*, east of them), or else that it shifted itself to this position during its early history; that in the vicinity of the present village of Rockford the drainage turned to the west, cutting across the edges of the strata, and that it deepened its valley in this position as the strata were elevated—gradually establishing itself in approximately the position now occupied across the Knobstone, the Lower Carboniferous limestone, and the Mansfield sandstone. Even though this entire region may have been approximately baseleveled since the orginal drainage was established, elevation subsequent to the baseleveling would have re-established the main drainage along its original lines.

The width of the valley throughout its length from the Muscatatuck to the Coal-measures suggests an age greater than has elapsed since the ice invasion, and makes the above explanation seem probable. The present course of the stream through its gorge below the mouth of the Muscatatuck cannot be explained by stream capture, if it be supposed that East White River originally entered the Ohio in the neighborhood of New Albany. If

it originally entered the Ohio near New Albany, its course below Rockford (*C*, Plate VI) would have been along the strike of easily eroded shales, and directly to the Ohio, a distance of fifty miles from Rockford. It is 150 miles southwest from Rockford to the mouth of the Wabash, through which East White River at present reaches the Ohio, and one-third of this distance is across the strike of resisting limestones and sandstones. It is obvious, therefore, that East White River could not have been captured at or below Rockford by a stream which flowed to the southwest across those hard strata. Moreover, there is no evidence to show that the former course of the stream was directly into the Ohio at New Albany.

Reversion, owing to elevation of the strata to the east and northeast is not regarded as a probable explanation of the lower course of White River, even if it be supposed that the original course of that stream was toward the east or northeast.[1]

The second hypothesis is as follows: It presupposes that prior to the ice invasion, the upper portion of East White River, (viz., east of the present mouth of the Muscatatuck) flowed either north or northeastward, or possibly emptied directly into the Ohio at New Albany—in any event that it flowed generally parallel with the Knobstone hills, east of those hills, and did not cut through them; that short tributaries of this main stream entered from the west, occupying about the courses of the East White and Muscatatuck rivers for fifteen miles above the present junction of those streams, but flowing in the opposite direction; that these short eastward flowing streams formed the triangular *cul de sac* in the Knobstone hills, in the center of which stand the Brownstown Knobs (*E*, Plate VI) with the Silver hills of Scott county (*D*, Plate VI) projecting east of the main line of hills; that west of the Knobstone escarpment the general drainage to the southwest was the same as at the present time[2] and that a

[1] The details of the preglacial drainage north and east from Rockford are obscured by the drift. The general preglacial contour of this part of the country, however, must have been about the same as that of the present time.

[2] In *Monograph XXXVIII, U. S. Geol. Surv.*, Pl. IX, Mr. Frank Leverett shows the supposed preglacial westward drainage of this region.

low pass was formed between the westward flowing streams and those flowing eastward which formed the corner of the *cul de sac* above referred to.[1]

During the glacial period the ice passed immediately east of the Knobstone hills in western Bartholomew county, through Jackson, and crowded up against the projecting knobs known as the Silver hills in Scott county (*D*, Plate VI). If the suggested conditions existed at that time, the triangular *cul de sac* in the Knobstone hills would have had its eastern outlet completely shut off by the ice, and the basin thus formed would have filled with water from the melting ice until it poured over the pass into the westward flowing streams; the pass would have been cut down, and finally the stream would have become firmly established in its new course, and into this it would have led the waters of its entire drainage basin as the ice retreated.

The shape of the *cul de sac*, in which the Brownstown hills stand with the eastward projecting Silver hills (*D*, Plate VI), against which the ice was pushed to the south, makes this second hypothesis seem probable. The principal objection to it is found in the general width of the valley of East White River below the mouth of the Muscatatuck. There are no *narrows* in the canyon to correspond with the position of the supposed original divide between the east and west flowing streams. The bottom, or present flood plain, of the valley varies in width from one-half mile to over one mile, and would certainly seem to antedate the ice invasion.

THE WESTERN DRAINAGE AREA.[2]

The main drainage lines of the western area are such as would be developed by the structure of the country, and they

[1] A condition of affairs quite similar to that hypothecated here exists at the present time in townships 1 south and 1 north, 5 and 6 east, where Muddy Fork of Silver Creek forms a triangular valley opening out to the east, while the divide between this stream and Blue River, which flows southwest is quite low. (*J*, Plate I.)

[2] The drainage of southern Indiana, in its relations to the glacial period, is discussed and mapped by LEVERETT in *Monograph XXXVIII, U. S. Geol. Surv.*, p. 97 *et seq.* See also Mr. LEVERETT'S discussion, Pt. IV, Eighteenth Ann. Rept. U. S. Geol. Surv., pp. 446–58.

are practically the same at the present as they were in preglacial times. The Knobstone sandstones, with their capping of limestones, rise in an eastward-facing escarpment unbroken, except where cut through by East White River, from the Ohio River at the south side of Harrison county to the northeast corner of Brown county. This escarpment rises from 200 to 400 feet above the lowlands of the central drainage basin immediately east of it, while to the west the country is rolling and descends gradually. The streams rising near the escarpment at the east flow down the gentle slope to the west and finally enter the Ohio, White, or Wabash rivers.

The control of the structure upon the drainage lines of this area is best seen immediately west of the Knobstone escarpment between the East White and the Ohio rivers (Plate VI). North of East White River apparently only the general course of the drainage is controlled by the structure; while in a general way the longest tributaries of the streams are those coming in from the east and northeast, this feature is by no means clearly marked, even in the area underlain by the comparatively hard Lower Carboniferous limestones and Mansfield sandstone.

It is noticeable that the streams of the western area which flow across both the area underlain by the Lower Carboniferous limestones and that underlain by the sandstones at the base of the Coal-measure (Mansfield sandstone) are not deflected as they pass from the limestone into the sandstone area.

The Mansfield sandstone is often massive and forms a rugged topography in the region in which it outcrops, and it might be expected that the streams would be deflected to the north or south by it. However, no such change in the stream courses is to be seen; instead of being deflected they pass directly from the limestone area across the sandstones, through which they have cut deep valleys, until they reach the comparatively flat region underlain by the soft Coal-measures shales at the west side of the Mansfield sandstone.

These conditions lead to the conclusion that the streams

from the land at the east cut directly across the Mansfield sandstone as it was first raised above the water and thus early established themselves in approximately their present courses.

In the region underlain by the soft sandstones and shales of the productive Coal-measures the only systematic arrangement noticeable in the streams is that of their general southwest directions.

Attention should be called in this connection to the sudden southward deflection of the east and west forks of White River, where these streams, after passing through the Mansfield sandstone areas, strike the area of the productive Coal-measures in Martin (*F*, Plate VI) and Greene (*G*, Plate VI) counties. The deflected portions of these streams are in a line with the south course of Anderson River between Spencer and Perry counties (*H*, Plate VI), in the extreme southern part of the state.

The coinciding deflections of these streams are suggestive, as they occur in a line approximately parallel with the position that must have been occupied by the shore line during a portion, at least, of productive Coal Measures times, and the suggestion is made that these streams had their courses turned parallel with the old shore line at that time, and that the streams have occupied approximately that position ever since. In this connection the south deflection of the Wabash near Covington and its due south course from Covington to Terre Haute, parallel to the above-mentioned portions of the two forks of White River and in a line with the southward deflection of West White River northeast of Vincennes (*I*, Plate VI), is of interest and suggests the same causes.

The region underlain by the Lower Carboniferous limestones is pitted with sinkholes and is often almost devoid of surface drainage systems, owing to the cavernous nature of those limestones and the well developed underground drainage in them.

East White River flows from the central across the western area and forms one of the principal streams of the western area.

North of the north line of Monroe and Brown counties the tributaries of West White River flow through glacial débris and

are left out of the discussion, as are also those streams that flow across the productive Coal Measures west of West White River.

SUMMARY.

In summing up the discussion of the drainage systems of southern Indiana attention is called to the following points:

1. The drainage in the region but thinly covered with drift, as well as in the driftless region, is controlled by the geologic structure.

The drainage (except in the eastern area) is toward the southwest, with the dip of the strata, and is such as would logically develop from a gradual elevation of a land surface, beginning at the east part of the state, and a corresponding recession of the water toward the southwest. The evidence points to the conclusion that the present drainage has developed from such an ancient initial drainage, and the writer believes this to have been the case.

2. The writer is unacquainted with any evidence in southern Indiana that the drainage has ever been toward the north and east.[1]

From above Madison to the southwestern corner of the state the Ohio River cuts more or less directly across successive groups of hard and soft strata. This is the position that would have been occupied by the stream had its course been developed across the groups of strata in question as those strata were gradually raised above the water at the west side of the land mass formed by the Cincinnati Arch, and a corresponding retreat of the water to the west. It is believed that the present course of the Ohio from and below the neighborhood of Madison has been developed from such ancient initial drainage—with many periods of comparative rest, and of activity, of course, corresponding with depressions and elevations of the land surface of the region traversed.

[1] See GERARD FOWKE, "Preglacial Drainage Conditions in the Vicinity of Cincinnati," *The Ohio State Academy of Sciences Special Papers*, No. 3, p. 68 *et seq.* Evidence is produced to show that the Ohio flowed northeastward in preglacial time, from near Madison.

If the preglacial drainage of southern Ohio and southeastern Indiana (the eastern area, of the present discussion) was toward the north and east, as some writers believe, then the watershed between such northeastward drainage and the southwestward drainage of Indiana was the highland formed by the Niagara and Devonian limestones, *i. e.*, the present watershed between the eastern and central drainage areas of southern Indiana.

How far north this watershed may have extended cannot be conjectured, but it probably extended as far north as Clinton county, and east of that county.

3. It is believed that that portion of the state in which the preglacial topography and structure were similar to the present topography and structure of the driftless area had also preglacial drainage systems parallel in a general way with the present drainage systems of the driftless region. This includes most of that portion of the state which lies west of the southwestward dipping Niagara and Devonian limestones.[1]

(By "driftless region" is here meant that region in which it is obvious that the present drainage systems are not controlled primarily by the drift.)

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[1] The drainage through the north end of the central area, or trough — *i. e.*, in the region of Clinton county and northward from there — may have been toward the northwest, so far as the structure is concerned.

GLACIATION IN THE ATLIN DISTRICT, BRITISH COLUMBIA.

In the Atlin district of Northern British Columbia the topography east of the coast range is characterized by wide main valleys having a general elevation of a little over 2,000 feet above sea level; between these main valleys are groups of mountains separated by other wide but more elevated and sloping valleys.

Both of these valley systems show evidence of glacial action but both also appear to have been deep drainage channels before the advent of this glacial action, and, to have received since that period no great modification in their form.

The upper system of valleys, broad, flat and inclined at a moderate grade, look too big for the comparatively small and rapid streams which drain them. These streams moreover have only cut narrow gutters to no great depth below the general floor of these valleys.

In this district there is evidence of two glacial periods, a regional glaciation, and a local glaciation, in part, over the same ground, at a later time. There is also a present active and extensive local glaciation now going on in the coast ranges to the westward. The latter may be a survivor or remnant under more favorable conditions of the two former periods.

The earliest regional or Cordilleran glacier left its evidence upon the main valley floors, and upon the upper slopes of the highest mountain groups in the district, a difference of about 5,000 feet in altitude. The movement was in a northerly direction.

The later local glaciation may have been due to the action of a remnant of the regional glacier, but appears more likely to have been the result of a later dispersion from a local névé. This glaciation followed these upper valleys and slopes, leaving the upper mountain groups above their action.

Regional glaciation.— As evidence of the regional or Cordilleran glaciation may be taken the occurrence of foreign rounded bowlders or erratics upon the upper slopes of the more or less isolated mountains of this district.

A light colored feldspathic granite and jasper are occasionally found at heights of over 4,000 feet above sea level, and 2,000 feet above the lower main valleys.

Mount Minto rises steeply from Atlin lake to a height of 4,700 feet above it, and 4,000 feet above the surrounding flats. The base of this mountain is hornblende-biotite granite, the upper portion of it is hornblende porphyrite; resting upon this porphyrite, near the peak, are rounded bowlders of a light colored granite and jasper pebbles.

East of Teslin Lake, on the mountains above Ptarmigan Flats, there is a glaciated rock surface at a height of 5,490 feet above sea level, and about 3,000 feet above the floor of Teslin Valley, which is also glaciated.

Near this place there are bowlders of a peculiar granite, having large crystals of hornblende. Such granite was only seen in place in the high, massive range six miles to the south and westward, across the deep intervening valley of Hurricane River, over 2,000 feet below these opposite ranges. If this valley existed at the time of bowlder transportation, it appears to have had little directive power.

Local glaciation.— The local glaciation appears to have originated from the water shed between Atlin and Teslin lakes. This is a district of wide, upland valleys and arctic moors, for the most part above timber line.

Such local glaciers did not cap the mountain groups apparently, but filled in the depressions between them, acting as carriers and pulverizers of the local rocks only.

This glacial occupation seems to have been confined to these elevated flats and slopes, and the valleys leading down from them, in much the same way as with the present coast glaciers. At the present time these elevated valleys, which are sometimes over a mile wide, are largely covered with more or less assorted

gravels, bowlder clay and morainic material, all of which is quite local in origin, the country rock being itself local and characteristic.

Elevated valleys.— The lower portions of Pine and Spruce creeks are terraced, the middle portions have false bedded material and bowlder clay. The upper valley of Spruce Creek is covered with little hills of morainic material. Occasional bowlders of rock, foreign to the present drainage basin, are attributed to the erratics of the regional glaciation. (See accompanying photograph.)

The streams now flowing through these valleys appear small in comparison with the wide troughs through which they run. Although rapid, and at times torrential, these streams have only cut narrow gutters into the drift and the rock floor beneath it. In doing this they have cut down to an older pre-glacial drainage and stream bed. The direction, grade and level of these pre-glacial stream gravels is very much the same as that of the present creeks, Pine and Spruce. These earlier gravels were traced, and apparently undisturbed, for two miles along Spruce Creek, lying directly beneath the mantle of gray blue glacial drift. They contain coarse gold. If it is assumed that coarse gold is concentrated by mechanical action in fairly rapid streams these gold bearing gravels should have been on the stream bed of a pre-glacial V-shaped valley, otherwise they would not have represented concentrations from the adjacent mountains, unless, like the present streams, they derived their gold and gravels from earlier stream or glacial deposits.

It appears probable that these pre-glacial gravels existed in the ordinary V-shaped troughs of mountain drainage originally, and that, local ice action, cleared out and widened the existing valleys without doing much towards deepening them. Such action appears to be borne out by a consideration of the existing glacier immediately to the south of Atlin Lake.

Llewellyn Glacier.—From the southern shores of Atlin Lake, flat-bottomed, fjord-like valleys lead up to tongues or lobes of the Llewellyn Glacier. These ice fronts are, in some cases, only

a few feet higher than the level of the lake, and a mile or so back from it. The intervening valley is flatly floored with quicksand or gravel, and is at times a mile wide at the ice front.

A rather small collection of morainic dumps lies in front of the ice. Swift glacial streams issue from beneath the ice front over beds of quicksand or gravel. These are heavily charged with sand and silt, but do not appear to bring out coarser material. These streams remove much of the coarse medial morainic material as it is gradually dumped over the ice front, and this may account for the small terminal moraines.

These medial moraines form wide low ridges of unassorted rock matter, stretching far back into the ice field, until they are lost to sight on the skyline or beneath fresh fallen snow.

The ice front rises very gradually backwards into the nearly level field of ice and snow, which continue south and westwards to Taku Inlet and the Pacific coast, a distance of 60 miles.

The upper surface of this ice field is about 5,000 feet above sea level, or 3,000 feet above Atlin Lake. Out of the general level of this inclined plain, mountain groups and peaks project, leaving wide, level gaps between them. Near the ice fronts the glacial surface is traversed by many small streams, which soon fall into crevasses. These probably supply most of the water which issues from the glacier front. Water action must be very slight within the interior region of the main glacier.

It appears that any loose material formed on the projecting mountain sides above the glacier will be removed. Frost and snow slides are very active agents in breaking up rock masses. The broken material finds no angle of rest. It falls between the ice and the shore and becomes a grinding agent, or else is borne out to feed the great medial moraines, hence it seems that this glacial action is very largely a widening one, continually trimming the sides of its directing walls, and acting as a carrier.

In such a way it may have widened out the water-worn troughs of the preglacial drainage, leaving at times portions of the deep stream bed unremoved.

J. C. GWILLIM.

NELSON, BRITISH COLUMBIA.

ON THE OCCURRENCE OF APLITE, PEGMATITE, AND TOURMALINE BUNCHES IN THE STONE MOUNTAIN GRANITE OF GEORGIA.

Aplite and pegmatite.—Careful field study of the larger and principal granite areas in Georgia, by the writer, indicates the general absence of true aplites therefrom. They have been observed in association with the granite masses only at one locality in the state. Since the border portions of the granite masses are usually covered with a considerable depth of residual decay and are seldom exposed, it is not possible to say whether aplites as border phenomena exist, as described by Kemp,[1] in some of the southern Rhode Island and Connecticut granites.

Several aplite dikes less than six inches in width are exposed in the quarries opened on the northwest side of the huge doming ridge known as Stone Mountain, sixteen miles east of Atlanta (Plate VII). Pegmatites are common associates in the Stone Mountain granite and also in the other larger granite masses examined in the state. They consist chiefly of coarse intercrystallizations of potash (orthoclase and microcline) and soda (albite) feldspars with quartz, subordinate amounts of both biotite and muscovite, and occasionally red garnet and tourmaline. So far as my observation goes, the feldspars in the pegmatite greatly exceed in amount the quartz. The granitic pegmatites are sometimes replaced, however, by those of practically pure quartz. In the Stone Mountain pegmatites the dark minerals, mica, tourmaline, and garnet, are frequently concentrated along the central axis of the dike or vein, rather than distributed through the light-colored quartz-feldspar portions. Where observed the granitic pegmatites are monotonously alike, and present no unusual features.

The principal aplite in the Stone Mountain granite is banded with pegmatite, the aplite forming the border next the granite

[1] *Bulletin Geol. Soc. Amer.*, 1899, Vol. X, p. 372.

Stone Mountain, Georgia. An unreduced residual of granite, rising 686 feet in elevation above the surrounding Tertiary Piedmont plain. Seven miles in circumference at its base. (Photograph by W. S. Y.)

and the pegmatite the middle layer of the dike. The junctions between the granite, aplite and pegmatite are regular, entirely sharp and well defined. Apart from its being more compact and of much finer-grained texture, the aplite is easily distinguished in the hand specimen from that of the inclosing granite by its lighter color—marble white—and by its containing but little mica. Biotite is entirely absent and muscovite is only sparingly distributed through the rock as minute foils. Occasional very small crystals of red garnet are sometimes present.

In thin section the aplite shows no essential difference in mineral composition from the granite, except in the entire absence of biotite and decreased muscovite. The rock is a holocrystalline mass composed chiefly of the potash (microcline and orthoclase) and soda feldspars, and quartz. Microperthitic structure consisting of interlaminated orthoclase and microcline with a second feldspar, albite, is common. Somewhat irregular, stout laths of a well striated acid oligoclase are numerous. The small percentage of CaO, less than 1 per cent., and the increased Na_2O shown in the analysis, column I, indicates the preponderance of the soda molecule (albite), which is corroborated by the microscope. Sporadic inclusions of apatite occur.

Megascopically, the inclosing rock is a compact, medium-grained biotite-bearing muscovite-granite of light gray, nearly white, color. Biotite is only sparingly distributed through the rock, displaying considerable tendency to segregate in places. Thin sections of the granite show quartz, orthoclase, and microcline frequently intergrown with albite as microperthite, considerable oliogclase, muscovite, occasional biotite, and some prismatic inclusions of apatite.

The striking similarity between the inclosing granite and aplite is sufficiently shown in the chemical analyses of the rocks given below.

The analyses show more SiO_2 and less K_2O in the aplite than in the granite, with close agreement indicated in the other constituents. A striking feature of the analyses is the low

	I.[1]	II.	Ia.	IIa.
SiO_2	74.30	72.56	1.2383	1.2093
TiO_2	none	.....	.....	.....
Al_2O_3	14.73	14.81	.1444	.1452
Fe_2O_3[2]	0.78	.....	.....	.....
FeO	.....	0.85	.....	.....
MnO	trace	.....	.....	.....
CaO	0.90	1.19	.0161	.0212
BaO	none	.....	.....	.....
SrO	none	.....	.....	.....
MgO	strong trace	0.20	.....	.....
Na_2O	4.61	4.94	.0743	.0796
K_2O	4.52	5.30	.0481	.0563
H_2O (Ignition)	0.21	0.70	.....	.....
P_2O_5	trace	.....	.....	.....
Total	100.05	100.55		

I. Aplite, Stone Mountain, Georgia. Watson, analyst.

II. Stone Mountain granite inclosing aplite. Packard, analyst.

Ia. Molecular ratios of I.

IIa. Molecular ratios of II.

percentage of lime with practically no magnesia, and increased soda, which equals in amount the potash, indicating the predominance of the albite molecule over that of the anorthite, and in case of the aplite the nearly entire absence of magnesia harmonizes with the absence of a ferro-magnesian accessory. Calculating all the lime as anorthite, all the soda as albite, and all the potash as orthoclase or microcline, the mineral-composition of the aplite and granite becomes:

	Aplite.	Granite.
Potash-feldspar	26.69	31.14
Soda-feldspar	38.77	41.95
Lime-feldspar	4.45	2.50
Quartz	28.30	21.09
Excess of Al_2O_3	.61	.....
Excess of Fe_2O_3	.78	.....
Excess of FeO	.....	.85
Excess of MgO	.....	.20
Excess of CaO	.....	.67
Excess of H_2O	.21	.70
	99.81	99.10

[1] Analysis *made* in the chemical laboratory of Denison University.

[2] All iron determined as ferric oxide.

In the aplite there is an access of Al_2O_3 after deducting the amount required of the feldspathic contituent of .0059 molecules corresponding by weight to 0.6 per cent., which is probably combined as mica. From the above calculations the ratio of soda feldspar to lime feldspar is 9 : 1 in the case of aplite and 17 : 1 in the case of the granite, corresponding to lime-bearing albite of Ab_9An_1 and $Ab_{17}An_1$ respectively, when the albite and anorthite molecules are combined to form soda-lime plagioclase. The potash feldspar in both the aplite and granite is part orthoclase and part microcline. According to the calculations the relative abundance of the constituents in the aplite may be expressed as follows: Oligoclase > quartz > orthoclase and microcline > muscovite. In the case of the granite the potash feldspars are slightly in excess of the quartz, otherwise the order of relative abundance of the constituents is the same as for the aplite.

	I.	II.	III.	IV.	V.	VI.
SiO_2	75. 7	76.03	76.00	74.21	77.14	74.30
TiO_2	0.09	0.07	0.04	0.30	0.29	none
Al_2O_3	13.07	13.39	14.88	14.47	12.24	14.73
Fe_2O_3	0.61	0.48	0.65	0.35	0.29	0.78
FeO	0.39	0.31	0.10	0.50	1.04	....
MnO	trace	trace	trace	none	trace	none
CaO	1.49	1.28	0.19	1.71	0.35	0.90
SrO	0.03	trace	none	trace	....	none
BaO	0.14	0.04	trace	none	....	none
MgO	0.14	0.05	0.06	0.28	0.06	strong trace
K_2O	5.62	5.18	2.77	0.10	4.47	4.52
Na_2O	2.51	2.98	3.52	7.62	4.64	4.61
Li_2O	trace	none	0.20	trace	....	....
H_2O at 100°	0.14	0.15	1.42	0.15	0.14	0.21
H_2O above 100°	0.24	0.34		0.23		
P_2O_5	trace	0.03	0.11	0.07	....	trace
	100.44	100.33	99.94	99.99	100.66	100.05

I and II. Potash aplites. Described by H. W. Turner, JOUR. GEOL., 1899, Vol. VII, p. 160; also *Seventeenth Ann. Rept. U. S. Geol. Surv*, p. 521. W. F. Hillebrand analyst.

III and IV. Soda aplites. Described by H. W. Turner, JOUR. GEOL., 1899, Vol. VII, p. 152. III, W. F. Hillebrand, analyst. IV, H. N. Stokes, analyst.

V. Aplite. Described by H. S. Washington, JOUR. GEOL., 1899, Vol, VII, p 107. H. S. Washington, analyst.

VI. Aplite. Stone Mountain, Georgia. Thomas L. Watson, analyst.

The percentage ratio of the alkalies in aplites, potash and soda, forms a ready basis for grouping them into potash-aplites, soda-aplites, and aplites of equal potash and soda percentages. The Stone Mountain aplite, as shown in the analysis, forms a striking illustration of the third or last type in which the percentage ratio of the potash to soda is equal. To make more emphatic this grouping, and for convenience of comparison, I have tabulated above analyses of some of the recently described well-known aplites from the eastern and western United States:

Tourmaline areas.—A noteworthy feature of the Stone Mountain granite is the somewhat abundant occurrence of small areas of aggregated black tourmaline crystals throughout the entire mass of granite, so far as revealed by quarry operations. Hardly a block of the stone is quarried that does not show a few of these areas. The occurrence of the mineral is not that of a characterizing accessory, as has been noted in some granites, as at Predazzo in the Tyrol, in which the tourmaline takes the place of mica or amphibole, but is more after the order of segregations in the biotite-bearing muscovite granite. Neither are the tourmaline aggregates sufficiently numerous and crowded together in the granite, nor of large enough size, to add to the color of the rock. While clearly visible in every case they do not in any measure detract from the good qualities of the stone for building purposes, for the reasons already stated, and also because of the practical unalterable nature of tourmaline under normal atmospheric conditions.

The tourmaline rarely occurs as isolated or single crystals in the granite proper, but nearly always as radiating and roughly parallel groups, which occupy the centers of perfectly white areas of quartz and feldspar, from which the two micas, muscovite and biotite, have been excluded. The quartz-feldspar areas vary in size from a fraction to several inches in diameter, according to the number of grouped single tourmaline individuals occupying it; and in shape they vary from oblong, irregularly rectangular to complete spherical or circular outlines, with all gradations between. The tourmaline individuals consist of slender pris-

A view of one of the quarries opened on the northwest side of Stone Mountain, Georgia. Aplite-pegmatites exposed in places over the floor of quarry, now clear of the quarry waste shown in the foreground of the photograph. (Photograph by W. S. Y.)

matic forms, varying from a fraction to several millimeters in cross-section without terminal faces; jet-black in color; and in every case examined they are considerably fractured. The number of individuals in a group varies greatly, usually from a half dozen or thereabouts to several times that number. The width of the border zone of the feldspar-quartz areas, or that portion of the white mass extending from the outer part of the tourmaline aggregate to the junction formed with the gray granite, is also variable, but is wider in proportion to the size of aggregate occupying the center, and is apparently proportional therefore to the intensity of the action controlling the tourmaline formation.

The quartz-feldspar areas are as strongly contrasted in color with the light gray granite as are the black tourmalines. The junction between the areas and the granite are entirely sharp and distinct, and in no case observed is there any tendency shown toward a gradation or merging of color of the white mass into the granite.

A number of thin sections of the feldspar-quartz areas and their included tourmaline aggregates were examined microscopically. The sections indicated a mosaic of interlocking quartz and feldspar, similar in all respects to, and consisting of the same feldspar species as the granite. No difference in texture and size of the component grains from that of the granite is observed. With few exceptions the feldspars were perfectly fresh. Cataclastic structure is quite strongly accentuated in the feldspar and quartz grains, the cracks are rather wide, and are now filled with a colorless, high double refracting mineral. Primary muscovite is not present in those slides examined, but plentiful small foils of the mineral distributed over the feldspar surfaces are seen in places, and from its association must be regarded as distinctly secondary. In transmitted light the tourmaline is deep brown in color and strongly dichroic. It is closely associated with both the quartz and feldspar, filling at times the interspaces. It is more intimately associated with the feldspar, however, and its distribution through some of the large

microcline and oligoclase individuals as partially connecting irregular and ragged granules closely resembles the poikilitic structure. In some cases the tourmaline is entirely confined to the feldspar individual, while in others it cuts well into the quartz and feldspar grains in such way as to clearly indicate its subsequent formation. In cross-section the mineral appears in some cases to be irregularly rounded and granular rather than bounded by sharp crystalline boundaries, but most of it is so very irregular that it is best described as having an exceedingly ragged outline. In a few instances the prism faces are indicated under the microscope. The mode of occurrence of the tourmaline and its association with the feldspar suggests beyond reasonable doubt its derivation in part from the feldspar, by fumarolic action.

The tourmaline cannot be regarded as a product of contact phenomena, since it is generally distributed throughout the entire mass of granite, so far as quarrying operations extend—not more abundant at one point than at another. I have elsewhere shown[1] that the present granite ridge, Stone Mountain, is the unreduced remnant or "core" of a once more extensive mass. The evidence favoring this is that, on the north, west, and south sides of the ridge, a belt of the same granite, reduced to the same general level of the surrounding Tertiary Piedmont plain, skirts the ridge for a distance varying from a quarter to more than a mile in width. In this reduced granite zone numerous quarries have been worked yielding the same beautiful light gray nearly white Stone Mountain granite. The rock quarried in this zone is strikingly free from the tourmaline aggregates, less than a half dozen in all having been observed. The areas, then, are confined to the ridge portion of the granite mass, and do not characterize the border portions of the granite nor of the adjoining schist and gneiss where exposed.

Black tourmaline as isolated single crystals and aggregates is rather a common associate in the Stone Mountain pegmatites,

[1] *A Report on the Granites and Gneisses of Georgia, Geological Survey of Georgia.* In press.

and in several instances veinlets of twelve and more inches long of tourmaline-felt (fine acicular tourmaline), as much as an eighth of an inch in width, have been noted in the granite in the northwest quarries of the ridge. While no distinct evidence bearing on the contemporaneous origin of the tourmaline aggregates in the granite with those of the pegmatite and the tourmaline veinlets, it seems reasonable to assume such contemporaneity.

The very nature of the areas oppose the hypothesis of direct secretion out of the eruptive granite magma. On the other hand, the characteristic mode of occurrence and intimate relationship to certain other mineral species present, as shown both macroscopically and microscopically, make it reasonably certain that the tourmaline areas have resulted from fumaroles highly charged with boric acid acting on the feldspars and mica.

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ICE WORK IN SOUTHEASTERN MICHIGAN.

OUTLINE.

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INTRODUCTION.

Owing to its geographic position, lying directly athwart the southwestward movement of the great Laurentide ice-sheet, with the maximum extent of international boundary, far enough distant from the great center of ice accumulation as well as from the southern limit of its movement, the state of Michigan must theoretically have borne the brunt of the Canadian ice invasion. Surrounded as is no other state by rock-basins, only partially occupied by our present Great Lakes, the evidence is not wanting that the Laurentide ice operated with exceptional vigor over the two peninsulas and the adjoining regions. So far as at present known, the most extensive and interesting exposures of ice activity within the state are to be found in the southeastern counties of Wayne and Monroe, bordering Lake Erie and the Detroit River. The following report upon this region is based mainly upon work carried on for the Michigan Geological Survey and is here published with the consent of State Geologist Dr. Alfred C. Lane. The series of Huron-Erie moraines, which lie to the west of the Upper Maumee beach in Washtenaw and Lenawee counties, as well as the beach itself, were traced upon the accompanying map from field maps of Mr. Frank Leverett, to whom the writer is indebted for many suggestions concerning the interpretation of the glacial features of this region.

GENERAL TOPOGRAPHY.

Surface topography.—With the exception of the extreme northwestern corner of Wayne, the two counties especially considered here were under the waters of the series of glacial lakes Maumee, Whittlesey, and Warren, which were ponded back by the

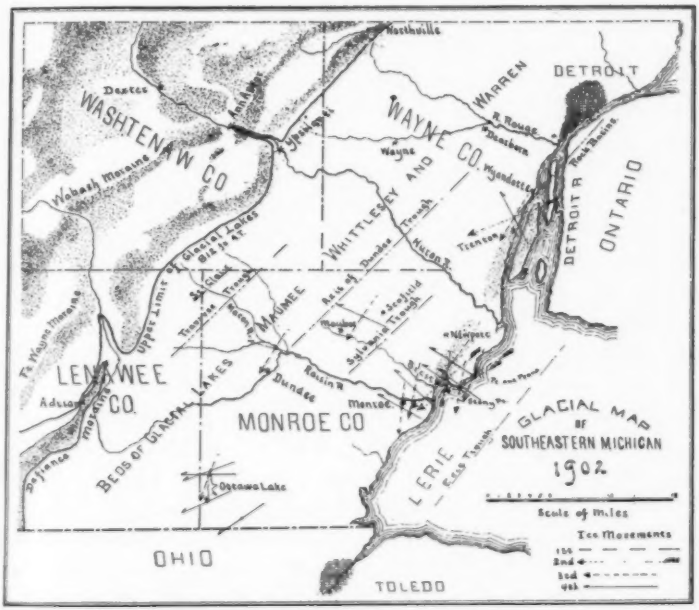

FIG. 1.—Glacial map of southeastern Michigan, showing the general directions of the four movements of the Laurentide ice. The upper limit of the glacial lake waters and the moraines to the west were located from the field maps of Mr. Frank Leverett.

late Wisconsin ice as it slowly retreated to the north and east. The result of this was that the surface elevations left by the ice-sheet were, in the main, leveled by the waves and currents while the depressions were silted up and there was produced a remarkably flat topography, the slope of which is discoverable only by the surveyor's level or the small streams which meander over this plain. The general surface rises very gently, six to seven

feet to the mile, from the level of Lake Erie (573 feet A. T.) outwards towards the Belmore beach. The evenness of this slope is shown in the left half of Fig. 2, although the slope itself is much exaggerated by the vertical scale adopted. This Belmore beach, which was made by the waves of glacial Lake Whittlesey, has a northeast and southwest course in this region, parallel with the Detroit River and present beach of Lake Erie and some eighteen to twenty-five miles inland. For over three-quarters of a century this "ridge" has been recognized as marking a higher stage in the lake waters, but it seems to have been the only one which was so recognized. The position of the Upper Maumee beach, recently traced by Leverett, is shown in Fig. 1, marking the highest limit of glacial waters. The elevation of this beach, just west of Ypsilanti, was determined during the past summer by the United States Topographical Survey as 812 feet, A. T. Between these two beaches there is a strip varying in breadth from two to six miles, having an average slope upward and outward of twelve to thirty feet to the mile. Throughout this narrow strip the topography is more uneven, the morainic hills not having been completely obliterated by the waters of glacial Lake Maumee, thus testifying to its limited breadth in this region, or to its short duration. To the west of the Upper Maumee the land becomes markedly morainic, due to the crowding together of the various members of the Huron-Erie series, which are entirely separate in Ohio and Indiana. Some of the knobs in the northwestern part of Washtenaw county attain a height of 1,000 to 1,100 feet, A. T.

Between the Belmore beach (739 feet, A. T.) and the present Erie beach there are found three approximately parallel belts of sand which mark different stages in the history of glacial Lake Warren. In certain sections this sand has been scattered by the winds and tossed into dunes, which give some relief to this otherwise flat topography. Three small river systems, the Rouge, Huron, and Raisin, have been developed since the retreat of the ice, and drain this region to the southeast. A few small creeks reach the lake and the Detroit River independently.

Rock topography.— Throughout the main region under discussion the bed rock consists, in descending order, of Genesee shale (St. Clair), Hamilton shale and limestone (Traverse), Corniferous limestone (Dundee), and Waterlime dolomite with an intercalated bed of very friable sandstone (Sylvania). The strata have a general northeast and southwest strike and dip to the northwest at an angle of two to five degrees. An embossment of rock, ten to twenty miles broad, underlies the greater part of Monroe county, and extends northeastward into Wayne, gradually dropping toward Detroit. The highest elevation attained by this bed rock is about 680 feet, at the head of Ottawa Lake, southwestern Monroe county. Upon the broad crest of this embossment are carried three minor ridges, one in the eastern part, another in the central, and the third toward the western part of the two counties. These ridges seem to correspond with the strike of the layers, and presumably consist of somewhat harder rock. They furnish the various natural and artificial exposures now available for study, the most northern of which is at Trenton (see Fig. 2).

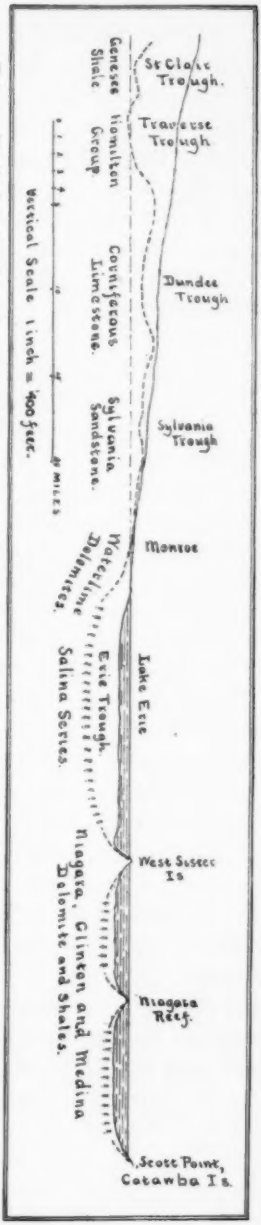

FIG. 2.—Vertical section from the northwestern corner of Monroe county, through Monroe to Scott Point, Catawba Island. The full line represents the surface of the land and the lake bottom; the broken line represents the rock surface, so far as it is known. Based upon the Lake Survey charts, railroad elevations, and individual well records.

Between these ridges lie two broad, shallow troughs, which have been named from the geological beds out of which they have been carved, the Dundee and the Sylvania.[1] The trend of these trough-like valleys is indicated upon the map, and also their extent, so far as recognized. The Dundee is the more pronounced of the two, having a breadth of two to four miles, and sloping downward towards Detroit at the average rate of four to five feet to the mile. Towards Dundee it is broader, and less well defined, as shown in Fig. 2. It seems to have been carved from the richer and softer strata of the Corniferous limestone, but in Wayne county it continues its direct course, while these strata are deflected eastward. Were it not for the deposit of drift, this trough would be filled with an arm of the lakes as far south as the southern boundary of Wayne county, standing one hundred feet deep at Detroit. The Sylvania trough begins in the west-central part of Monroe county, cutting eastward across the Waterlime dolomite until it strikes the outcrop of Sylvania sandstone, when it turns northeastward and becomes more accentuated in that portion which lies parallel with the Dundee The valley then follows the strike of the Sylvania sandstone eastward and flattens out. In the northwestern part of Monroe county there occurs a double trough cut from the Genesee shale and the Hamilton shales and limestones, the latter being the best defined and having the same general direction and slope as the Dundee trough. The slope northeastward averages some nine feet to the mile so far as it has been followed in the well records. Were the drift removed, this trough would also be filled with water to a distance of three to four miles into Monroe county.

In the southern half of the eastern part of this county the rock surface drops rather rapidly towards Lake Erie, although the rock strata dip in the opposite direction, thus showing that much material has been removed by some agencies. The drop averages twenty-five to thirty feet to the mile, bringing the rock surface about one hundred feet below the Erie level by

[1] *Geol. Surv., Mich.*, Vol. VII, Pt. I, 1900, p. 122.

the time the lake is reached, forming the western slope of a very much larger trough underlying the western end of Lake Erie. An inspection of the Lake Survey chart shows that the eastern slope of this broad trough is terminated by a rock-ridge upon which are located West Sister Islands and Middle Sister Islands, running S. 35° W. Northeastward, towards the Ontario shore, occur Colchester reef and other rock. Toward the southwest this broad trough is continued beneath Toledo for a long distance as the Maumee trough, which would be filled with water were the drift removed, standing one hundred feet deep at Toledo, and extending seven miles further west than at present along the Ohio-Michigan line. Eight miles east of the ridge above-mentioned there occurs a second one running across the lake S. 32° W., and indicated by Niagara reef, East Sister Islands, and several other shoals and reefs. Between these ridges a second trough reaches across the lake, having its axis parallel to all the others. Beyond the second ridge, and between it and the string of islands which stretches continuously from Catawba Island northeasterly to Pointe Pelée, there is a narrower and less well-defined trough, but parallel to the two other Erie troughs. The position of this series of troughs, their direction and approximate parallellism, their shape, and, so far as known, their direction of slope toward the northeast, all suggest that the primary agency was ice, acting with exceptional vigor straight out from the center of Laurentide accumulation. It so happened that the strike of the rock-strata in this region coincided with the main axis of ice movement, and the troughs in all cases were formed in the softer beds. It is not improbable that preglacial streams occupied some of these valleys, as in the case of the Sylvania, and that where the valley had the same trend as that of the ice movement it received the maximum ice erosion. The ice mass appears to have been too great at this stage to permit of its following the valleys when they turned aside from its general course. We seem to have here, but on a much larger scale, a similar phenomenon to that observed by Gilbert in western New York.[1]

[1] *Bull. Geol. Soc. Am.*, Vol. X, p. 121, 1899.

DRIFT OF THE REGION.

Till.—A mantle of typical Wisconsin till covers the rock, except over the limited areas where the rocks are naturally exposed, or where it has been artificially removed about the quarries. This would average from forty to fifty feet in thickness in Monroe county, and perhaps seventy-five to eighty feet in Wayne. In the Traverse trough the drift is 140 to 150 feet thick, somewhat less beneath Detroit and Windsor. Westward toward the Defiance moraine the till thickens in Washtenaw county to two hundred feet west of Ypsilanti. We have no evidence of more than one sheet of this till. Occasional well records in southern Wayne and northern Monroe counties speak of seams of a black, combustible substance, generally referred to as "coal," but no continuous layer of black soil or peat exists. "Hard-pan" is not infrequently mentioned, and it is not improbable that isolated patches of early Wisconsin or pre-Wisconsin till may have escaped the late Wisconsin ice. At present writing, the twelve-foot shaft of the Michigan Rock Salt Co. has just penetrated seventy-one feet of till at Ecorse, just south of Detroit. This section gives four feet of muck; two feet of mucky clay; four feet of a mottled lake clay, yellow, brown, and blue in color, with shells, but no pebbles; and some seventy feet of soft, bluish-drab till, carrying pebbles and bowlders. The only break in this sheet of till was found at a depth of thirty feet, where a six to eight-inch layer of gravel was encountered. In certain regions the till may be discolored to a depth of several feet, the maximum being fourteen, as reported at Dundee. Generally, blue clay can be found quite near the surface. Bowlders are distributed sparingly over the two counties, lying upon the surface or embedded in the deposits from the glacial lakes. Huge masses of limestone, of the nature of "transported ledges," have been found in the till and mistaken for outcrops of bed rock.[1]

[1] WINCHELL, "Some Indications of a Northward Transportation of Drift Materials in the Lower Peninsula of Michigan," *Am. Jour. Sci.*, 2d ser., Vol. XL, pp. 331–38. Also *Geol. Surv. Mich.*, Vol. VII, Pt. I, p. 22.

Moraines.—The moraines of the region mapped belong to the Huron-Erie series, and have a northeast and southwest direction. The most easterly and youngest is a water-laid moraine consisting of continuous and very symmetrical till ridges from five to twenty feet in height. They make their appearance between Wyandotte and Trenton, swinging in from the islands of the river, and they may be followed southward to within a mile of the Huron River. South of the river the moraine is indicated only by an unusual bunching of cobble-stones to the east and southeast of Newport. In the vicinity of Brest there is a suggestion of morainic topography, the ridges running eastward into the lake and apparently marking the southern limit of this moraine. This is probably Taylor's Detroit moraine,[1] although it has not yet been followed into Ontario. The Defiance moraine lies just west of the Upper Maumee beach, the position of which it determined in this region. It is a relatively narrow moraine of comparatively weak expression, containing low knobs of sand and gravel, some of which were submerged by glacial Lake Maumee. Westward, the members of the Huron-Erie series become more and more massive, and so crowded that they cannot with certainty be distinguished from one another. Between them lie outwash gravel plains and ancient drainage channels, through which the water from the ice escaped to the west.

ICE ACTION IN WAYNE COUNTY.

Late Wisconsin.—Although there are rock exposures upon the islands of the Detroit River and near Gibraltar, still the surface of the waterlime dolomite is so much weathered that the striæ are entirely obliterated. Undoubtedly they are preserved under the heavier covering of till, but these portions of the rock-surface have not yet been exposed. The most favorable locality in the county for the study of glaciated rock is at the extensive Sibley quarry, operated by Church & Co., one mile north of Trenton, and about fourteen miles south of Detroit.[2]

[1] JOUR. GEOL., Vol. V, No. 5, 1897, p. 423.

[2] The station "Sibley's" may be reached from either Detroit or Toledo very conveniently by either steam or electric cars.

The rock here consists of heavily bedded and remarkably pure Corniferous limestone which is being quarried for building purposes, road metal, and the manufacture of beet sugar and soda ash. Some thirty-five acres have been opened about which there is always to be seen a variable margin of glaciated surface from which the till has been stripped. A huge embossment of rock here represents the northern terminus of one of the rock ridges described previously. The rock surface dips in all directions from the crest, but less rapidly towards the southwest, so that conditions were most favorable here for receiving and recording the effects of any ice-sheet moving across this region from the west, north, or east.

The marginal strip of rock surface, nearly a mile in length, shows pronounced glaciation by the late Wisconsin ice-sheet. The limestone has been planed down, striated, and gouged, and to a slight extent polished, but there are no furrows. The striæ and gouges have a rather unique northwestward direction, forty-eight observations about the quarry giving an average of N. 28.8° W. (true reading), with a range of 43° (N. 43.5° W. to N. 0.5° W.). The general appearance of the rock surface, with its intersecting gouges, is shown in Fig. 3.

The direction of ice movement is fully attested by a variety of phenomena, which were all clearly described by Chamberlin in 1888.[1] Striæ are frequently found of the nature of the one shown in Fig. 3, beginning as a fine scratch, passing gradually into a gouge and ending abruptly toward the northwest, as the stone was suddenly crushed. Projecting masses of the bed rock were bruised and scratched upon the southeast side, while the northwest side is rough and unglaciated. "Chatter-marks" are numerous with their convexities invariably turned toward the southeast and "plucking" is frequently to be seen upon the northwestern side of the elevated ledges. Previously formed furrows which have a northeast-southwest direction have their northwestern sides bruised and rounded, while the southeastern sides of these furrows meet the general rock surface with a well

[1] *Seventh Ann. Rept. U. S. Geol. Surv.*, p. 244.

defined angle and generally retain the earlier set of striæ. The most interesting and conclusive of all these evidences of the direction of ice movement is that of the so-called "knobs and trails."[1] These are now to be seen on the northern and northeastern sides of the quarry, and five years ago also upon the southern side. Certain layers of the limestone contain silicified

FIG. 3.—View of the late Wisconsin glaciation, Corniferous limestone, Sibley quarry, showing parallel and intersecting striæ and gouges. Looking northwest in the direction of ice movement. At the right of the small satchel is a gouge fourteen feet long, N. 20° W., which begins as a pin-scratch but gradually broadens northwestward, expanding distally to four inches and terminating abruptly.

fossils and irregular nodules of chert. On account of their superior hardness these were worn away less rapidly by the ice than the limestone in which they are embedded and consequently they project above the surface. On the northwest side of many of these knobs there are found "trails" of limestone which diminish in height gradually to the general surface of the lime-

[1] GILBERT, *Geol. Surv. of Ohio*, 1873, Vol. I, p. 539.

stone but maintain the breadth of the protective knob. This phenomenon is shown quite clearly in Fig. 4. As a rule narrow and relatively deep furrows were plowed out in front of and at the sides of the knobs, the lateral furrows being prolonged a considerable distance backward before they disappear. Of the

FIG. 4.—"Knob and trail" phenomena produced by the late Wisconsin ice-sheet, testifying positively to the direction of northwest movement. Northern part of Sibley quarry. The main central gouge shows "chatter-marks" indistinctly in its lower half, while in the upper part of the view there are evidences of "plucking." A shallow, tortuous groove crosses the left hand portion of the slab, cut subsequently to the glaciation by a small stream of water flowing between the rock and the till covering.

various properties imputed to ice for the purpose of explaining the movement of glaciers, *plasticity under pressure* can alone satisfactorily explain this phenomenon of "knobs and trails," with their frontal and lateral grooves.

Associated with this late Wisconsin glaciation, but slightly later and cutting across it some 18° further to the west, as though made by a slight advance of the ice, is an erosion feature not known to have been previously noted. This is to be seen at the southwestern corner of the quarry, where it will be destroyed in a few more months, as the quarry is being extended in that direction. This consists of patches of miniature rock basins and narrow grooves, crowded together, in approximately parallel positions and covering some three to four square yards, so far as at present exposed. The limestone here is shattered, but essentially homogeneous, and has the appearance of a pavement formed of irregular blocks with edges rounded. The patches of basins are more conspicuous upon those blocks which are slightly higher than their neighbors and are better defined toward the stoss side of the blocks. It was found impracticable to get the basins to show satisfactorily in a field photograph, in which the lighting could not be controlled, so plaster casts were made of a number of patches for detailed study. Fig. 5 gives a reduced view of a cast, with the mold from which it was made at the left.

The basins are typically of a more or less elongated elliptical shape, sharply outlined, rather shallow and have the steepest slope toward the iceward side. The distal sides of the basins show a more gradual slope up to the general rock surface. The deepest part of the basin is either at the center, or placed nearer the iceward end, as is the case with the larger rock-basins of heavily glaciated regions. Some of the basins can be observed only with the help of a magnifier, while the largest noted has a length of 35^{mm}, a breadth of 15^{mm} and depth of 2^{mm}. Considering those of all sizes they are very numerous and closely placed, occasionally overlapping and superposed. The interiors of these basins are very generally perfectly smoothed and slightly polished, although with a magnifier delicate scratches may be detected. Occasionally some are seen which appear rough and have a bruised appearance. Some of the basins become elongated into U-shaped troughs, which may be either straight or curved. In the case of the curved ones the slope is

much steeper on the concave side, with a well defined crest, while that upon the convex side of the curve is less steep and flatter. This is the reverse of what we find in the case of stream erosion. In places these troughs have the appearance of branching and anastomosing, but this is probably due to the overlap-

FIG. 5.—Mold and cast of a patch of miniature rock-basins, Sibley quarry. The ice movement was from above, downward. The continuous parallel grooves which pass diagonally across the cast were made by the preceding (late Wisconsin) ice movement, but were slightly emphasized by the movement which produced the basins. Careful examination of both the cast and mold will show that the miniature ice currents were deflected by these grooves for a short distance, but that the general direction was then resumed.

ping of those which have the curved form. Indeed, we have here in miniature glacial canyons, fjords, and a great variety of rock-basins, showing all their essential characteristics. If these have been difficult to account for satisfactorily how much more

so will be these toy affairs, for which differential ice action can scarcely be invoked! Pebbles embedded in the ice do not come into action suddenly and do not thus gouge the rock. Hard pebbles from about which the clay may have been washed and upon which the ice during its slight readvance may have settled could hardly have been thus forced into the limestone by the plastic ice. If the ice was not plastic then what became of these pebbles, there being no evidence of their having been crushed in the basins or troughs? These are some of the difficulties the writer has encountered in trying to arrive at an explanation of the phenomena.

Early Wisconsin.— Previous to the glaciation just described there was a general and more vigorous movement south-southwest across this region, which must be referred to the early Wisconsin stage. On the north side of the quarry there are to be found "lee and stoss" phenomena, "knobs and trails" and the above described effect upon the distal side of previously formed furrows. The general effect upon the rock surface was very largely obliterated by the late Wisconsin ice and the striæ and gouges are preserved mainly in furrows made by this earlier sheet itself or in those already in existence when it invaded this region. The mean of twenty-one observations taken on all sides of the quarry gives for the general direction of movement S. 30.8° W., with a rage of 19.5° (S. 20.5° W. to S. 40° W.). This direction makes an angle of 120° with that of the late Wisconsin in this vicinity, it is manifestly older and there is evidence that it acted more vigorously, was presumably more massive and capable of reaching further south.

Iowan?— A still earlier set of striæ than that above described is to be seen in certain rock-basins and troughs partially exposed at the northeastern part of the quarry, and in some of less size at the southeastern part. At the time of a visit to the quarry five years ago a few readings were made in a trough which has been since partially removed, these readings averaging S. 64° W. During the past fall fifteen additional readings gave a mean of S. 68.6° W., with a range of 12.5° (S. 65.5° W. to S. 78° W.).

Most of these were made at the southwestern end of a partially uncovered rock-basin, or trough, across which they cut in such a way as to show that the basin was already in existence when they were formed upon its distal side. The striæ are shown in Fig. 6, emerging from the basin toward the right and diagrammatically in Fig. 7, upon the upper side, marked second move-

FIG. 6.—Southwestern end of a rock-basin, Sibley quarry; partly filled with till and water. Two sets of striæ are seen emerging from the basin; the set at the left being early Wisconsin, that toward the right pre-Wisconsin, probably Iowan. The basin itself is believed to have been formed by the Illinoian ice. In the background is seen the effect of the late Wisconsin upon the projecting ledge, with stoss phenomena toward the southeast.

ment. An inspection of this diagram shows why they were not obliterated by the third, or early Wisconsin ice, being slightly in the lee of the western side of the basin. They are here intersected sufficiently, however, in order to settle the question of their relative age. Their position is such as to have rendered their removal probable by the late Wisconsin ice, but either its

weight was not great enough to force it into the basin sufficiently, or else the basin was filled with till. So far as observed the evidence is that the ice producing these striæ acted less vigorously than did the early Wisconsin sheet. It does not seem to have produced any furrows or troughs of sufficient size to escape obliteration at the hands of the two later sheets. There may be a question as to whether this set of striæ should not be connected with the early Wisconsin described. Its general direction of movement differs, however, by some 38° and the two sets lack 25° of coinciding at their limits. Undoubtedly a larger number of readings would tend to connect the two series in this region, but further south they diverge still more widely. In the rock-basin figured this set lacks that freshness of appearance which characterizes the Wisconsin scorings and it is believed to be pre-Wisconsin, probably Iowan. The general direction of movement harmonizes with what is known concerning the distribution of the Iowan drift, its relative age and the intensity of ice action are also consistent with this view. Further, the Iowan ice is known to have crossed this region, and such an independent sheet would have been much more liable to have left its record than would simply a minor advance of either the early Wisconsin or the Illinoian.

Illinoisan.— At the northeastern corner of the Sibley quarry there is at present a series of partly uncovered rock-basins, one of which is shown in Fig. 6. This has an apparent breadth of twenty-five to thirty feet, is eight to ten feet deep and some eighty-five to ninety feet of its length are in sight. There are four other basins, or troughs, in this same vicinity having with this one the approximate directions S. 37° W., S. 54° W., S. 39° W., S. 36° W., and S. 43° W. A small one running S. 17° W., belongs more probably with the preceding stage of glaciation. At the southeastern corner of the quarry a heavy double furrow running S. 45° W., contains pre-Wisconsin striæ and is to be included in the series. The average trend of these basins is found to be S 42° W. These basins lie upon the stoss side of the Sibley embossment, where they were plowed out by

the ice as it was forced up and over the slope. The rock here is of uniform hardness over the area affected so that the basins were the result of differential ice action. A glance at Fig. 1 shows that the general direction of these basins corresponds perfectly with that of the troughs previously described, and the conclusion is irresistible that they were all made by the same ice-sheet, which moved very steadily straight out from the center of Laurentide accumulation to the southernmost limit of glaciation in southern Illinois. It is apparent that this sheet acted with a vigor far in excess of that of any previous sheet, that it showed an utter disregard of topography; indeed, it seems probable that it had more to do with the *making* of our present rock topography, than the other three sheets combined. These facts suggest that it was the most massive of the Laurentide sheets and presumably able to reach a more southern latitude than any of the other three, that it was in reality the Illinoian. The following diagram will serve to make clear the relation of the striæ to the principal basin.

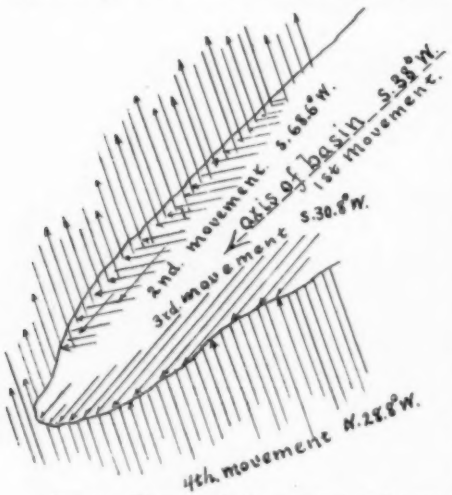

FIG. 7.— Diagram of the principal rock-basin at present exposed at the Sibley quarry. The arrows indicate the direction of each general movement, numbered in order from the first, or Illinoian. The central part of this basin is still covered with till.

Rock-shattering.— It has been observed in all the quarries and natural exposures in southeastern Michigan that the upper three to five feet of limestone strata are much shattered and apparently thin bedded. The strata become more solid and have the

appearance of being more heavily bedded as they occupy a deeper position in the series. The same stratum dipping from the surface may have the disrupted condition just beneath the till which is shown in Fig. 8 and still be as solid and compact at a depth as the lower strata shown in this figure. This condition of the rock is believed to have been caused by a tremen-

FIG. 8.— View showing shattered condition of the upper strata at the Sibley quarry, west wall. This is believed to be due to the slow creeping movement of a vast ice-sheet, combined with the subsequent action of frost.

dous weight of ice slowly and spasmodically creeping over the rock surface, the effect of which was to open up the inconspicuous sedimentation seams to a considerable depth. This permitted the entrance of water, the freezing of which would tend to completely disrupt the strata and give them the thin-bedded, shattered appearance.

SCORINGS IN MONROE COUNTY.

Eastern portion.— This county furnishes more numerous exposures of the rock surface than does Wayne, but none are

so extensive as that at the Sibley quarry. At many of the localities where rock comes to the surface it is in such weathered condition that all scoring is obliterated. In the eastern part of the county, in the vicinity of Monroe, there are six accessible localities where well preserved striæ may be studied. The most northern of these is the Sissung quarry, one and one-half miles southeast of Newport. Here the two sets of Wisconsin striæ are seen, the late Wisconsin being the more abundant and averaging N. 57° W., having swung 28° further west from their direction at Sibleys. The early Wisconsin striæ maintain nearly their same direction, averaging S. 37° W. As early as 1839 the striæ at Brest and Point aux Peaux were observed and reported upon by Bela Hubbard, an assistant upon the first geological survey of the state.[1] At the former place he found two sets N. 50° E. (S. 50° W.) and N. 65° W. At Point aux Peaux he reported but one set N. 60° E. (S. 60° W.), which is to be correlated with those of the second movement at Sibley's (Iowan ?). At the present time the only striæ seen here have a general direction of S. 21° W., representing the early Wisconsin, the late Wisconsin not being exposed. Some twenty years after Hubbard's observations were made Winchell took the bearings of striæ which had been exposed by the waves at Stony Point. These he found to extend N. 60° W. and S. 60° W.[2] The writer now finds at this locality the two Wisconsin sets, averaging N. 54° W. and S. 10° W. At Brest the same two appear N. 57° W. and S. 9° W. At the quarry of the Monroe Stone Co., three miles southwest of Brest, the striæ average N. 48° W. and S. 12° W. Just south of the city of Monroe, at the Plum Creek quarries, we find them running N. 61° W. and S. 6° W. A comparison of the above data with those at Sibley's shows that the late Wisconsin striæ have shifted toward the west, the early Wisconsin toward the south, and that the supposed Iowan appears only at the three localities nearest the Erie shore, this representing the stoss side of the Monroe embossment for this movement. The general direction of this series is more south-

[1] *Second Ann. Rept. State Geologist*, p. 113. [2] *Report for 1860*, p. 127.

westerly. At most of these localities the late Wisconsin are the most abundant, although the early Wisconsin are well represented, testifying to the more energetic nature of the latter sheet. The amount of range in the direction of the striæ of the two Wisconsin series is very notably less in this region than to the west and north. This is to be explained by the fact that we are here nearer the axis of the Huron-Erie lobe, along which the movement was theoretically only slightly divergent.

Central portion.—The only satisfactory exposure of striæ upon the central ridge of the county is found at the Woolmith quarries, in the north central part of the county, between Maybee and Scofield, upon the Detroit & Lima Northern Railroad. The striæ of the two Wisconsin glaciations are well preserved about the main quarry, but those of the earlier series are more conspicuous. Thirteen readings give an average of S. 34.1° W., with a range of 27° (S. 22.5° W. to S. 49.5° W.). The late Wisconsin series is alone found in the small Hoffman quarry to the south. From both quarries twenty-two readings were taken and found to average N. 65.7° W., with a range of 40° (N. 91.5° W. to N. 51.5° W.). It is of interest to note that here, upon the Macon and at the Sibley quarry, some distance out from the main axis of movement, when a considerable number of observations were made, the range is from 40 to 50°, or about 25° on either side of the mean. It is not probable that doubling or trebling the number of readings would much alter the amount of this range. This amount of divergence is due to the fact that the ice moves out continually at right angles to the margin of the lobe, as pointed out some years ago by Chamberlin.[1] In the case of such a lobe as the Huron-Erie of the late Wisconsin ice, with its main line of movement toward the southwest, at any point some distance to the north of this central axis the striæ would have a more northerly course when the lobe was small and be deflected more and more to the west as the lobe increased in size. Theoretically the striæ on the northward side of the mean direction of movement should indi-

[1] *Seventh Ann. Rept. U. S. Geol. Surv.*, 1888, p. 201.

cate less vigorous ice action than the striæ upon the opposite, or westward side of this mean.

Western portion.—Upon the western rock ridge the finest exposures of striæ are to be found north of Dundee about the mouth of the Macon River. As these are in the bed of the Macon and Raisin, the best time for a visit is in the late summer or early fall when the water is low. The past season proved favorable and a satisfactory set of readings was obtained. The most conspicuous scorings to be found were made by the early Wisconsin, thirty-six observations giving a mean of S. 32.2° W., with a range of 46.5° (S. 3.5° W. to S. 50° W.). The rock ledges in the bed of the Raisin, just below the entrance of the Macon are heavily gouged by this series. The late Wisconsin sheet seems to have had but little effect upon the rock surface as the series of moraines was approached. At but one locality in the bed of the Macon are any striæ of this series to be found, giving a mean of N. 74.3° W. The movement becomes more westerly as we pass southward and south of west as the Ohio boundary is reached. At the head of Ottawa Lake a limited exposure shows the two sets S. 89° W. and S. 21° W. Just north at the quarries the few readings averaged S. 70° W. and S. 25° W. At the "Inlet" a single gouge runs S. 65° W. and three miles to the southeast in the bed of Halfway Creek four readings were obtained giving a mean of S. 56° W. In thus passing southward we approach the main axis of the late Wisconsin lobe and its striæ again predominate over those of the early Wisconsin.

GENERAL CONSIDERATIONS.

1. There is no evidence in this section of Michigan of any general southeasterly ice movement.

2. All the scoring action observed may be referred to four stages in the history of the Laurentide ice-sheet.

3. The first and oldest ice movement was to the southwest, being the most vigorous of all, quite independent of topography and presumably the most massive. Parallel with the main axis of the Illinoian glaciation its reference to this stage of the

Laurentide ice seems justified. About the western end of Lake Erie where the strike of the softer beds coincided with the direction of ice movement, broad, shallow troughs were excavated.

4. A second general movement followed west-southwesterly, intermediate in point of time between the Illinoian and early Wisconsin and less vigorous than either. This glaciation probably represents the Iowan.

5. The third ice movement was south-southwestward, second in vigor and massiveness only to the Illinoian and presumably capable of attaining also a low latitude. This is quite certainly the early Wisconsin. This ice is believed to have produced the series of outer discordant moraines in southern Ohio and Indiana. With this evidence, so far back from the southern limit of the Wisconsin ice, of distinct difference in direction of movement, in steadiness, vigor, and massiveness, more of a break between the early Wisconsin and late Wisconsin probably existed than has been yet recognized.

6. The fourth and final movement was the late Wisconsin, which resulted in the formation of the concentric morainic loops of northern Indiana, northwestern Ohio, and eastern Michigan. The ice was more influenced at this stage by the topography than at any previous time, was less vigorous and presumably less massive. The movement was in the main southwestward, but upon the upper side of the Huron-Erie lobe was outward toward the moraines, having less and less effect upon the rock surface. As the ice front retreated northeastward water was ponded back in the low country of the Maumee valley, Lake Erie region and southern Lake Huron and the series of glacial lakes was formed.

7. In the region under report the rock surface was lowered but slightly by the three later ice-sheets, the amount to be expressed most probably in inches. Knobs and trails produced by the early Wisconsin in exposed position are but slightly affected by the late Wisconsin. Moderately heavy gouges and striæ of the early Wisconsin escaped obliteration in many

localities. The relation of the striæ to the rock-basin seen in Figs. 6 and 7 shows that the adjoining rock surface was but little lowered by the early Wisconsin. In the Lake Erie region the pre-Wisconsin gouges on flat surfaces were not obliterated by both Wisconsin sheets. So far as our rock topography in this region is due to ice action this was accomplished by the first movement, that of the Illinoian. Judging from what is known concerning the rock topography of the Great Lakes region, the writer ventures to suggest as a "working hypothesis" that the real axes of all the major troughs and rock basins throughout this wide area point approximately to the Laurentide center of ice accumulation and that they were produced by the earliest of the four general movements.

W. H. SHERZER.

MICHIGAN STATE NORMAL COLLEGE,
Ypsilanti, January 30, 1902.

Editorial.

In the United States Geological Survey the geologic branch is reorganized by the appointment of Mr. C. Willard Hayes to the position of geologist in charge of geology, to take effect March 1, 1902. Mr. Hayes has been connected with the Survey since 1887, and has served with ability in various relations as assistant geologist, geologist, and since 1900 as geologist in charge of investigations of non-metalliferous economic deposits. He is now placed in administrative control of the geologic branch in order that the director may be relieved of executive details and the organization may be strengthened by the undivided attention of its head to carrying out the director's general policy. By this appointment Mr. Willis, who since 1897, as assistant in geology to the director, has performed the administrative work of geology, is freed from that duty and will be at liberty to give more attention to the division of areal and stratigraphic geology, of which he has charge.

In announcing these changes at a meeting of geologists in the office of the survey on February 20, the director called attention to the plan of organization of the geologic branch set forth in the *Twenty-first Annual Report*, pp. 20 and 21, and more fully elaborated in the forthcoming *Twenty-second Annual Report*. The fundamental idea of the organization is that scientific direction and supervision may be and in most cases should be separated from administrative control. Specialists are placed in charge, each one of investigations in a particular subject, Becker, Chamberlin, Day, Emmons, Hayes, Stanton, Van Hise, and Willis having been thus appointed, but their authority is in general limited to consideration and approval of the scientific aspects of the work. Administrative authority remained immediately with the director, and is now in a degree transferred to the geologist in charge of geology, Mr. Hayes. B. W.

Reviews

Moræner i den Islandska Palagonitformation [Moraines in the Palagonite Formation in Iceland]. By Helgi Pjetursson. From Oversigt over det Konglige danske videnskabernes sellskabs forhandlinger, 1901, No. 5.

The author has before this[1] described the occurrence of ground moraines in the palagonite of Iceland. The present paper is a brief summary of this earlier account and a report on some later observations, with a statement of conclusions drawn from the same.

All former writers on the geology of Iceland have recognized as glacial deposits only such morainic accumulations as overlie the palagonite, and the latter has been regarded as a Tertiary eruptive containing local aqueous sediments. The present author finds ground moraines in palagonites and breccias lying under doleritic lavas that have heretofore been regarded as preglacial. The material is indurated and stony, cut by joints and dikes, but has the characteristic texture of ground moraines. He thinks that there can be no reasonable doubt that this material is of glacial origin, and he presents four good reasons for his view, viz.:

1. The structure of the beds.

2. The nature of the included blocks. These are usually somewhat rounded. Quite often they exhibit beautiful scorings. One of the most perfectly scored bowlders the author had ever seen, he found in a "breccia" 100 feet thick, which appears as a gray belt on the bare rocky wall of Búrfells.

3. The "breccias" in some cases may be seen to rest on typically striated bed rock.

4. In some places where "breccias" resembling moraines rest on basalt, the upper surface of the latter is broken into fragments, which are worked into the base of the "breccia." One can see that some blocks of the basalt lie near where they were broken off, while other blocks have been carried farther away and are mingled with somewhat rounded bowlders.

[1] See *Scottish Geographical Magazine*, May, 1900.

These old glacial deposits occur on the north as well as on the south side of the island and frequently have a considerable thickness. At times lavas are interbedded in a way which suggests close proximity in time of the volcanic and the glacial forces. At other places there appear to be indubitable proofs of a general absence of glacial conditions at times of great volcanic activity. Doleritic lavas with their upper surface scored by the latest moraines, rise several hundred feet above old eroded surfaces of earlier glacial drifts. How many there are of the latter one cannot yet definitely say. Apparently there are more than one. It is noted that all these older moraines are associated with the palagonite tuffs, and there is some reason to think that they were made at some period during Miocene-Pliocene time. This, the author remarks, is a strange indication, in view of the what is known concerning the glacial age on the continent. But further investigations are needed to determine the age. The relation of the moraines to some fossil-bearing crags on the north coast promises more light on this question.

In the south half of the island the breccia plateau was for the greater part built after the moraines were made. The principal relief features of the land, as for instance the south lowland, are younger than even the uppermost of the palagonite moraine.

The heavy and extensively distributed ice-scored doleritic lava flows, show that there was a long interglacial period, for they overlie unconformably older moraines. The fossil-bearing crag at Tjörnes, already referred to, may prove to belong to this stage. Heretofore this deposit has been regarded as belonging to the Pliocene.

J. A. Udden.

The Cement Industry. Descriptions of Portland and Natural Cement Plants in the United States and Europe, with Notes on Materials and Processes in Portland Cement Manufacture. Reprinted from the *Engineering Record*, New York.

This interesting series of papers gives a very fair idea of the development of the cement industry at the time of their first publication a few years ago. Originally written for the *Engineering Record* by S. B. Newberry, Frederick H. Lewis, and others especially interested in cement, as independent articles describing typical cement plants of Europe and America, they are now published, together with an appro-

priate introductory chapter on the nature of material suitable for Portland and natural cement. Considerable space is devoted to a description of kilns, intermittent, continuous, ring, and rotary, and their relative merits are fully discussed. In the thirty or more plants which are described in detail, the wet, the half-wet, and the dry processes are represented, and the criticisms of the authors in regard to the fitness of each process for the material used is, on the whole, judicious. If the writers were preparing a series of articles today, however, they would probably include in their descriptions a larger percentage of mills using hard material, and have occasion to lay more stress on the ball mill as a suitable device for grinding. The matter is presented in a practical way, with numerous diagrams and illustrations. The impression is given that the American cement industry compares favorably with that of Germany, and that both of these countries now outrank England, the first producer of Portland cement. The trade in general is beginning to realize this fact, and today American cement is not discounted by the foreign product.

The volume is a useful one both for students of economic geology and technology, and for those otherwise interested in the manufacture and use of cements.

F. A. W.

Adephagous and Clavicorn Coleoptera from the Tertiary Deposits of Florissant, Colo., etc., etc. By S. H. SCUDDER, Monograph XL, U. S. Geological Survey.

PROFESSOR SCUDDER'S investigations upon the fossil insects of the Florissant basin are well known. In Monograph XXI of the United States Geological Survey the rhynchophorous Coleoptera of North America were fully treated, and the present monograph is a temporary completion of the descriptions of North American Tertiary beetles. The new material described is nearly all from the Florissant basin, and is confined almost exclusively to the Adephagous and Clavicorn families. In addition to the new material described, however, a complete systematic list of the known non-rynchophorous Tertiary Coleoptera of North America is given, with bibliographic references and notes on geographic and geologic distribution. A large amount of new material from various western localities still remains to be studied, which will doubtless add much to our knowledge of these Tertiary insects.

S. W.

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